

**U.S. DEPARTMENT OF COMMERCE
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PB-289 777

**Management of Bottom Sediments Containing Toxic
Substances: Proceedings of the 3rd U.S.-Japan Experts'
Meeting, Held at Easton, Maryland in November 1977**

(U.S.) Corvallis Environmental Research Lab, OR

Sep 78

United States
Environmental Protection
Agency

Environmental Research
Laboratory
Corvallis, OR 97330

EPA-600/3-78-084
September 1978

Research and Development

PB 289777



Management of Bottom Sediments Containing Toxic Substances

**Proceedings of the Third U.S.-
Japan Experts' Meeting**

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U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

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TECHNICAL REPORT DATA (Please read Instructions on the reverse before completing)		
1. REPORT NO. EPA-600/3-78-084	2.	3. REPORT NUMBER PB289777
4. TITLE AND SUBTITLE Management of Bottom Sediments Containing Toxic Substances: Proceedings of the Third U.S.-Japan Experts' Meeting -- November 1977, Easton, Maryland	5. REPORT DATE September 1978	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Spencer A. Peterson and Karen K. Randolph, editors	8. PERFORMING ORGANIZATION REPORT NO.	
9. PERFORMING ORGANIZATION NAME AND ADDRESS Environmental Research Laboratory--Corvallis, OR Office of Research and Development U.S. Environmental Protection Agency Corvallis, Oregon	10. PROGRAM ELEMENT NO. 1BA608	11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS same	13. TYPE OF REPORT AND PERIOD COVERED inhouse	14. SPONSORING AGENCY CODE EPA/600/02
15. SUPPLEMENTARY NOTES Proceedings of the Second U.S.- Japan Experts' meeting on Bottom Sediments is EPA-600/3-77-083		
16. ABSTRACT The United States-Ministerial Agreement of May 1974 provided for the exchange of environmental information in several areas of mutual concern. This report is the compilation of papers presented at the Third U.S.-Japan Experts' Meeting on the Management of Bottom Sediments Containing Toxic Substances, one of the 10 identified problem areas. The first meeting was held in Corvallis, Oregon, in November 1975. The second meeting was hosted by the Japanese Government in October 1976. The third meeting (at which these papers were presented) was held in November 1977 in Easton, Maryland. <i>Some of the areas discussed are: toxic effluents; water pollution control projects; dredging; toxic sediments and the impacts associated with dredging; bioassays; spoil disposal and regulation.</i>		
17. KEY WORDS AND DOCUMENT ANALYSIS		
a. DESCRIPTORS water reclamation sanitary engineering contaminants water pollution ocean bottom sediments freshwater bottom sediments	b. IDENTIFIERS/OPEN ENDED TERMS toxic sediments mercury, PCB contamination of sediments water pollution pollution elimination/control dredging	c. COSATI Field/Group 06/F 08/A,C,J,H 13/B,J,
18. DISTRIBUTION STATEMENT Release to Public	19. SECURITY CLASS (This Report) Unclassified 20. SECURITY CLASS (This page) Unclassified	21. NO. OF PAGES 309 22. PRICE PC A14 MFA01

EPA-600/3-78-084
September 1978

MANAGEMENT OF BOTTOM SEDIMENTS CONTAINING TOXIC SUBSTANCES

Proceedings of the Third U.S.-Japan Experts' Meeting
November 1977 -- Easton, Maryland

edited by

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FOREWORD

Effective regulatory and enforcement actions by the Environmental Protection Agency would be virtually impossible without sound scientific data on pollutants and their impact on environmental stability and human health. Responsibility for building this data base has been assigned to EPA's Office of Research and Development and its 15 major field installations, one of which is the Corvallis Environmental Research Laboratory (CERL).

The primary mission of the Corvallis Laboratory is research on the effects of environmental pollutants on terrestrial, freshwater, and marine ecosystems; the behavior, effects and control of pollutants in lake systems; and the development of predictive models on the movements of pollutants in the biosphere. The United States-Japan Ministerial Agreement of May 1974 provided for the exchange of environmental information in several areas of mutual concern. This report is the compilation of papers presented at the Third U.S.-Japan Experts' Meeting on the Management of Bottom Sediments Containing Toxic Substances which was held November 15-17, 1977 in Easton, Maryland. The first meeting was held in Corvallis, Oregon, in November 1975. The second session was hosted by the Japanese Government in October 1976. The 1979 meeting will be held in Japan.

A. F. Bartsch, CERL Director
and U.S. Coordinator for the
U.S.-Japan Experts' Meeting

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CONTROL OF TOXIC EFFLUENTS AND MANAGEMENT OF TOXIC BOTTOM SEDIMENTS

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INTRODUCTION

In recent years, the decline in Japanese water quality has ceased and there has been a trend toward slow recovery. Water pollution caused by cadmium and other toxic substances has stabilized and pollution from organic substances has, since 1969, definitely slowed -- even improved in certain areas. This is due to the rigorous control of effluents throughout the country in recent years. However, there are still areas where water pollution is severe, especially in rivers that run through cities with high populations and heavy industrial concentrations and in bays and inland seas where exchange rates with the sea are slow.

This paper explains the water pollution control measures designed to regulate the discharge of toxic substances and treat bottom sediments containing toxic substances.

MERCURY

The organic mercury poisoning which afflicted the inhabitants of Minamata and Niigata focused considerable public attention on the problem of mercury poisoning. This attention was heightened in 1973 by the suspected mercury contamination in Ariako Bay, which caused the government to call a conference on June 12, 1973, to establish countermeasures against mercury pollution. The conference, under the chairmanship of the Director-General of the Environmental Agency, adopted a series of measures to control mercury pollution, including a nationwide environmental survey, improved standards and vigorous administrative guidance for those industries involved as sources of the contaminants.

SURVEY OF MERCURY POLLUTION

The nationwide comprehensive environmental survey was conducted in areas where mercury contamination of fish products was reported (prior to 1973) and in areas adjacent to mercury-handling factories and mercury mines. Fish products, water quality, bottom sediments, soil and agricultural products were examined.

The 22,403 samples of fish products examined during the investigation included 303 species collected from 268 aquatic sites (124 inland and 144 marine). The results showed that the contents of mercury pollutants in almost all of the samples of marine fish were below the provisional acceptable levels of 0.4 ppm of total mercury and 0.3 ppm of methyl mercury, and that most of the samples of river fish were also below acceptable levels. The government concluded that there was no cause to restrict fishing or sale of fish in most areas. However, in certain parts of Minamata Bay, Tokuyama Bay, the area off Naoetsu, and Kagoshima Bay, the mercury contents of certain species of fish exceeded the provisional acceptable level. Fishermen in these areas voluntarily refrained from fishing. The pollution of water and bottom deposits in Minamata Bay and Tokuyama Bay, and of water off Naoetsu is attributed to accumulated mercury-containing effluents discharged in the past from nearby factories. Although mercury content of fish in Kagoshima Bay exceeded the provisional level of 0.4 ppm total mercury, the mercury concentration in the water and bottom deposits was no different from those of other unpolluted marine areas. The polluted fish are attributed to the effects of volcanic activity on the floor of the bay.

Fishing in these polluted areas is still restricted today. Particular fish species caught in certain parts of nine rivers adjacent to mercury mines were found to contain mercury in excess of the corresponding provisional acceptable level. The inhabitants of the river basins have been warned against eating them. In inland and marine areas, where the problem of mercury pollution still remains unsolved, surveys of fish catches and fish products are being conducted regularly.

The survey of water quality involved a total of 3,768 samples taken from 634 sites consisting of 331 rivers, 156 harbors and 147 marine areas. Of these, 76 samples (2.0% of the total) were found to contain total mercury in excess of the environmental quality standards. These samples were traced to four rivers and two marine areas. The Environmental Agency will identify the cause of this pollution and take suitable measures to counteract it.

The survey of the quality of bottom deposits was made on a total of 5,656 samples taken from 647 sites consisting of 341 rivers, 158 harbors and 148 marine areas. The results showed bottom deposits from 27 sites (16 rivers and 11 bays) which contained mercury in excess of the provisional acceptable level.

To prevent additional mercury pollution it is essential to effectively treat mercury-containing effluents and to control disposal of mercury-containing wastes. The Water Pollution Control Law of 1971 extended regulation of effluents from a small number of regions to the entire nation. Effluent standards were established and those relating to mercury were made more stringent in 1974. The revised effluent standards have been an important factor in the dramatic improvement of the quality of effluents. By June, 1974, factories manufacturing acetylene-based vinyl polymer chloride and acetylene-based acetaldehyde (the two major sources of mercury-containing effluents) either discontinued their production, changed their processes or terminated effluent discharge outside the plant. The closing-off of effluents

from factories manufacturing caustic soda using the mercury process was completed at almost all factories by December, 1973. In addition, plans were made for a switchover from the mercury process to either the asbestos diaphragm or ion-exchange diaphragm process of manufacturing caustic soda. The schedule had aimed at two-thirds conversion by September, 1975, and completion by March, 1978. The interim goal of two-thirds conversion was reached by the end of FY 1975. However, the attainment of full switchover will be difficult under present circumstances because:

- (1) Caustic soda produced by the asbestos diaphragm process is not as readily accepted by consumers because of its lower quality.
- (2) Commercial development of the ion-exchange diaphragm process is not yet complete.
- (3) A large amount of capital is required to convert to the ion-exchange diaphragm process, and the caustic soda business has declined recently so capital is not readily available.

Therefore, accelerated development of the ion-exchange diaphragm process is urgently needed. It is important to continue to monitor effluents discharged from mercury-process factories until conversion has been accomplished.

REMOVAL OF MERCURY-CONTAMINATED SEDIMENT

To help prevent pollution of fish products from mercury-contaminated bottom deposits, provisional standards were established for the removal of polluted sediments on August 31, 1973. These standards were based on the permissible limits of mercury concentration in fish products (0.4 ppm of total mercury and 0.3 ppm of methyl mercury), food intake, biological accumulation of mercury (an overall accumulation coefficient of 1,000), release of mercury from bottom deposits, and its diffusion, mixing and other such factors in a given area.

As of January, 1976, bottom deposits in 39 water areas were found to be contaminated by mercury in excess of the provisional removal standards. Of these, 27 were found by the surveys conducted in fiscal year 1973 and an additional 12 areas were found in subsequent investigations. Sediment removal was completed in 29 areas, similar work is under way in 7 others and plans are being drawn up or detailed investigations under way in the remaining 3 areas.

PCB

A nationwide investigation of aquatic sites for PCB pollution was conducted in 1972 and 1973 concurrent with the mercury pollution survey.

Examination of 3,369 samples of seafood products for PCB contamination was made in the 20 areas which were found in previous surveys to be contaminated. Based on the findings of these examinations, voluntary regulation of fishing was put into effect in 16 of the areas, and catches are examined regularly.

A total of 1,281 water samples taken from 282 aquatic sites were examined. The samples covered 208 rivers, 28 harbors and 46 marine sites where fish products were found to be contaminated by PCB, and the bottom deposits contained more than 1 ppm PCB. Of the total, 55 samples (or 4.3%) were found to contain PCB in excess of the water quality standards and they were traced to 18 river areas and 4 marine areas. Efforts are being made to identify the cause of this pollution in order to establish appropriate measures to prevent further pollution. When compared with the previous year there are definite signs of improvement both in the frequency of detection and in the concentration of PCB.

The survey of bottom deposits examined a total of 1,789 samples taken from 354 sites covering 258 rivers, 38 bays and 58 marine sites. It was found that 51 areas containing 42 rivers, 5 bays and 4 marine areas had bottom deposits containing PCB in excess of the provisional removal standard of 10 ppm per unit dry weight. The examination also showed that bottom sediments at 6 sites contained more than 100 ppm, 8 sites contained from 50 to 100 ppm, 11 sites had from 25 to 50 ppm, and 26 sites had from 10 to 25 ppm of PCB.

CONTROL OF PCB SOURCES

The manufacture, use and importing of PCB has been totally banned since 1971 by administrative policy. It is now banned by law except for specifically authorized purposes. Even in such cases, the manufacturers are under instructions to maintain control on such products. Necessary measures are also being enforced to ensure the recall and proper storage of products containing PCB.

Many items such as discarded appliances, transformers attached to heavy-duty electrical machinery, condensers and pressure-printing duplicating papers contain PCB wastes. Measures have been established with the management of corporations and municipalities for the recall and storage of such wastes. Adequate disposal of such wastes is being carried out under the amendment of the Cabinet Order for Implementation of Waste Disposal and the Public Cleansing Law, made in December, 1975, and the enforcement of March, 1976 standards for disposal of wastes containing PCB.

REMOVAL OF PCB-CONTAMINATED SEDIMENTS

As with mercury pollution, provisional standards for the removal of PCB-contaminated sediments were also established. To start with, the findings of the 1972 investigations were used as a basis to set provisional removal standards at 100 ppm per unit weight of dry sediments. The nation-wide environmental surveys conducted in fiscal year 1973 provided new data on the basis of a statistical analysis of PCB concentration in sediments and on the permissible limits of PCB concentration in fish products, the removal standards were changed on February 28, 1975, to 10 ppm per unit weight of dry sediments.

Sediments in 86 areas were found to contain PCBs exceeding the provisional removal standards; 51 of them were found in the investigations conducted in fiscal year 1973 and 35 of them in other surveys. Projects for the removal of the contaminated sediments were completed in 25 of these areas and are under way in 20 others. Similar projects are planned for 9 areas and, as of December, 1975, further investigations are being conducted in the remaining 32 polluted sites. Most of the contaminated sediments are either buried on the premises of factories, contained in concrete pits, or are buried elsewhere.

RESULTS OF THE MEASURES TO CONTROL PCB CONTAMINATION

Measures employed for the control of environmental contamination by PCB include the establishment of environmental quality and effluent standards, removal of contaminated sediments, and improvements made in effluent treatment facilities. At present, the situation has greatly improved except in some areas where waste paper recycling factories are located. Pressure-printing duplicating papers containing PCB must be stored and some of them become unavoidably mixed with other waste papers.

SEDIMENTS CONTAMINATED BY OTHER HAZARDOUS SUBSTANCES

Besides mercury and PCB, sediments contain other hazardous substances. The important ones are heavy metals like cadmium, chromium, copper and zinc, and also petroleum. There are no investigations now under way for the study of those materials in water, bottom sediments or biota.

WATER QUALITY

The emphasis of measures designed to control discharge of harmful substances into the public waters of Japan has been directed toward the establishment of environmental quality standards and effluent standards as well as the improvement of water quality surveillance systems and waste water treatment. Table 1 demonstrates that these efforts have begun to bear fruit in the form of a dramatic decrease in the concentration of harmful substances in public waters.

The number of samples failing to meet the environmental water quality standards for cadmium and other toxic substances injurious to human health has decreased sharply year by year. Of the total samples in FY 1970 and 1975, respectively, the number exceeding the standard fell from 1.4 percent to 0.17 percent. Moreover, even though the standard for total mercury became stricter on September 30, 1974, there was no sample site at which the total mercury detected by water analysis exceeded that allowed by the new standard. As in previous years neither alkyl mercury nor organic phosphorus was detected in any of the FY 1975 samples.

TABLE 1. RATIO OF SAMPLES EXCEEDING ENVIRONMENTAL QUALITY STANDARDS FOR HARMFUL SUBSTANCES TO TOTAL SAMPLES

Substances measured	Fiscal year	No. of samples examined (A)	No. of samples exceeding the standards (B)	Ratio (%) (B)/(A)
Cadmium	1970	2,564	71	2.8
	1971	15,944	114	0.7
	1972	27,951	95	0.34
	1973	30,567	98	0.32
	1974	31,915	119	0.37
	1975	32,851	103	0.31
Cyanides	1970	2,187	33	1.5
	1971	12,453	142	1.2
	1972	22,223	113	0.5
	1973	23,969	49	0.2
	1974	25,060	16	0.06
	1975	26,037	4	0.02
Organic phosphorus	1970	1,865	3	0.2
	1971	5,116	11	0.2
	1972	12,004	0	0
	1973	11,403	0	0
	1974	12,304	0	0
	1975	10,713	0	0
Lead	1970	2,222	61	2.7
	1971	14,515	202	1.4
	1972	27,067	181	0.7
	1973	30,228	166	0.55
	1974	31,818	118	0.37
	1975	31,939	101	0.32
Chromium (hexavalent)	1970	552	12	0.8
	1971	11,532	15	0.1
	1972	22,437	15	0.07
	1973	23,856	20	0.08
	1974	25,438	8	0.03
	1975	25,722	4	0.02

continued

TABLE 1 (continued)

Substances measured	Fiscal year	No. of samples examined (A)	No. of samples exceeding the standards (B)	Ratio (%) (B)/(A)
Arsenics	1970	1,942	20	1.0
	1971	11,530	48	0.4
	1972	21,991	64	0.29
	1973	23,848	75	0.31
	1974	26,005	71	0.27
	1975	28,447	67	0.24
Total mercury	1970	2,228	22	1.0
	1971	12,360	32	0.3
	1972	22,727	8	0.01
	1973	24,611	3	0.01
	1974	(25,901)	(50)	(0.19)
	1975	(29,879)	(74)	(0.25)
Alkyl mercury	1970	1,603	0	0
	1971	5,624	0	0
	1972	10,968	0	0
	1973	12,590	0	0
	1974	12,246	0	0
	1975	11,695	0	0
PCB	1975	3,063	10	0.33
Total	1970	16,164	222	1.4
	1971	89,074	504	0.6
	1972	167,368	476	0.3
	1973	181,072	411	0.23
	1974	164,786	332	0.20
	1975	179,534	291	0.17

Source: The Environmental Agency

Remarks: On September 30, 1974, the method for the measurement of total mercury was changed, with the result that the detectable limit was lowered. However, under the new limit, no instance was reported in which the total mercury contents exceeded the environmental quality standards.

SEDIMENT CONTAMINATION SURVEY

A sediment contamination survey has been under way since 1973 to investigate the level of hazardous substances in sediments all over the country.

Surveys were conducted as follows:

- 1973: Detailed investigations in major aquatic areas near mercury mines and factories manufacturing caustic soda by means of mercury-process electrolysis. PCB-handling factories were investigated in detail, and thorough investigations were conducted at other PCB-contaminated sites and at areas which were not contaminated.
- 1974: Investigations on mercury pollution in areas where the bottom deposits contained more than 5 ppm of mercury as determined by the investigation of the previous year. Investigations also were conducted for 3 major bays (Tokyo Bay, Ise Bay and Seto Inland Sea) and for 10 major lakes (Lake Biwa, etc.). Environmental surveys were conducted in areas where the removal of PCB contaminated deposits had been completed.
- 1975 - 76: Investigations in areas where the mercury or PCB concentration of bottom deposits exceeded 1 ppm as determined by previous investigations. Investigations were also made in areas where voluntary fishing restrictions exist and where warnings on eating contaminated fish are in effect. (See Tables 2, 3 and 4 for statistical details.)

TABLE 2. NUMBER OF AQUATIC AREAS INVESTIGATED

Year	Mercury			PCB			Total		
	Rivers	Sea areas	Sub-total	Rivers	Sea areas	Sub-total	Rivers	Sea areas	Sub-total
1973	341	306	647	258	96	354	599	402	1,001
1974	47	30	77	37	6	43	84	36	120
1975	132	71	203	99	32	131	231	103	334
1976	122	95	217	119	33	152	241	128	369

TABLE 3. REMOVAL OF CONTAMINATED SEDIMENT (Hg)
As of January, 1977

	Number of areas		
	Sea	River	Total
Completed	9	20	29
In progress	3	4	7
Planning stage	3	0	3
Total	15	24	39

TABLE 4. REMOVAL OF CONTAMINATED SEDIMENT (PCB)
As of August, 1976

	Number of water areas		
	Sea	River	Total
Completed	7	35	42
In progress	3	9	12
Planning stage	4	15	19
Total	14	59	73

PRESENT AND FUTURE WATER POLLUTION CONTROL PROJECTS IN JAPANESE RIVERS AND LAKES

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INTRODUCTION

Water pollution of public rivers and lakes in Japan has a magnified impact because of the limited water resources of the country. To prevent further deterioration of water quality, many water pollution control projects are being conducted under direct control or as grant-in-aid projects of the Ministry of Construction.

Originally rivers and lakes, especially those near large cities, were being polluted by domestic and industrial wastewater discharges which resulted in fish kills and noxious odors. More recently, water pollution has also affected smaller cities as well, and toxic materials such as mercury and PCB are accumulating in the beds of rivers and lakes.

To control water pollution at the source the government must set limitations on the discharge of industrial wastewater, encourage improvement of sewage processing facilities and eliminate direct discharge of pollutants into rivers (Figure 1). For rivers which are already polluted, the dredging of accumulated sludge and sediment in river beds or the introduction of clean water are methods which help to alleviate the problems.

HISTORY OF RIVER POLLUTION CONTROL PROJECTS

The Ministry of Construction started direct control of river water pollution control projects in 1959 with the Iwabuchi Gate project. This was to introduce clean water from the Arakawa River into the polluted Sumida River. The project was completed in 1962. After that came a project associated with the Tokyo Olympic Games in 1964 where water from the Tone Reservoir was to be discharged into the Ara River through the Musashi Channel. Water collected behind the Akigase Dam in the Ara River was to be introduced through the Asaka Channel into the polluted Shinkashi River located in the upper channel of the Sumida River. In 1967 the Neya River cleanup project, in which water from the Yodo River was introduced into the polluted Neya River, was completed as a project related to the International Exposition in 1970.

River water pollution control projects started as grants-in-aid from the Ministry of Construction in 1958. The first was a dredging project on the Sumida River. Many dredging projects near large cities such as Tokyo, Osaka, and Nagoya, were completed, but still failed to halt the deterioration of water

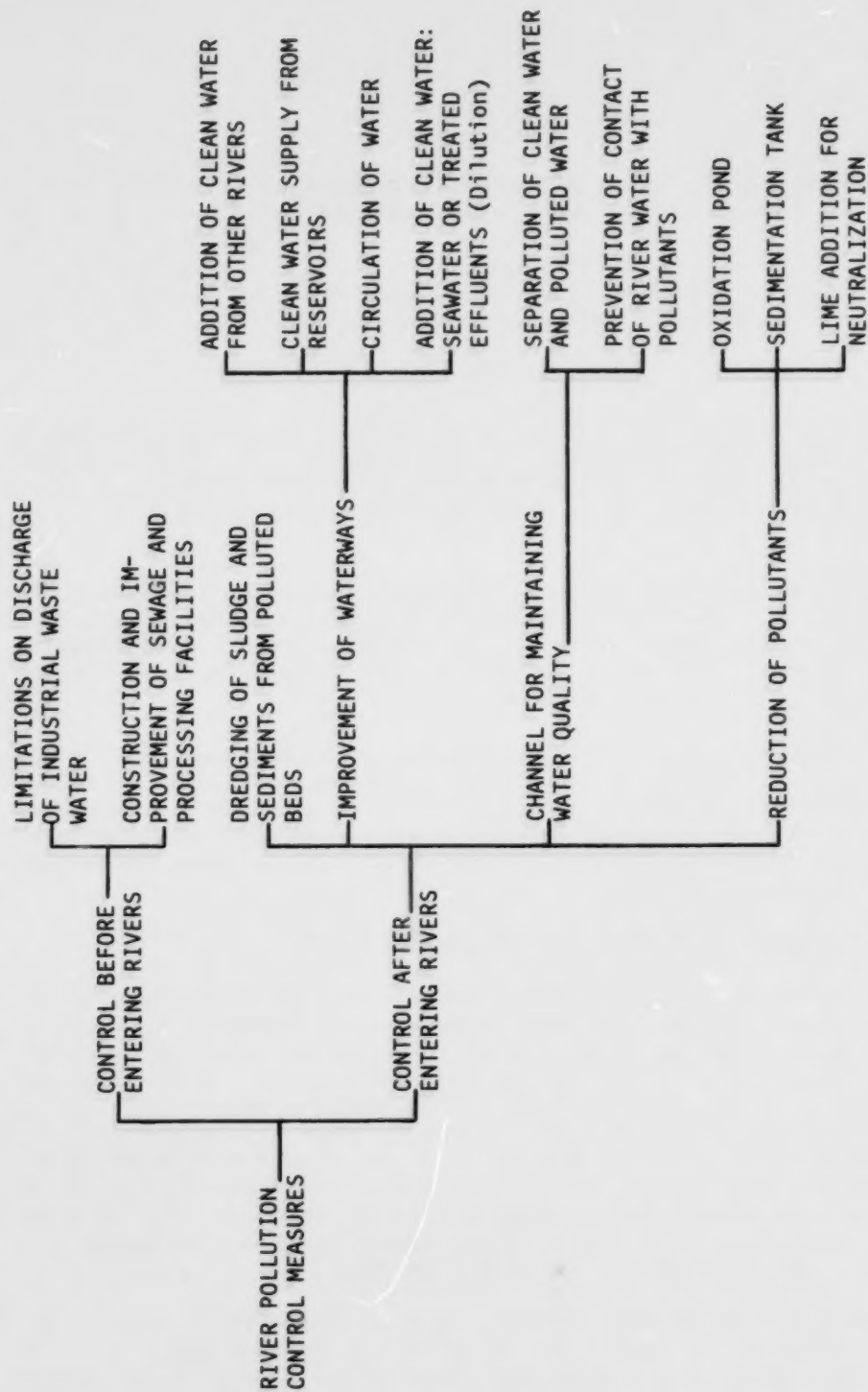


Figure 1. Pollution control measures.

quality near population centers. To cope with this problem the "Urban River Conservation Section" was created within the River Bureau of the Ministry of Construction. The budget item known as the "Urban River Environmental Improvement Project" included dredging of sludge and sediment, construction of water channels and improvement of river levees and beaches for the recreation of local citizens.

But environmental problems in rivers did not remain limited only to large cities. As a result, in 1974 the term "Urban" was deleted from the budget item, and money became available for improvement of every river with pollution problems. Tables 1, 2, and 3 list some of the improvement projects.

Dredging for control of river pollution is performed by the Administration of each river or by the person who discharges the effluent.

The definition of the term "person" is similar to that defined by the "Federal Water Pollution Control Act" in the United States, i.e., the term "person" means an individual, corporation, partnership, association, prefecture, municipality, commission, or political subdivision of a prefecture, or any interprefecture body.

There are two ways in which a private corporation contributes to the dredging of discharged sediments. One way is when the discharged sediments are dredged along with those others discharged from numerous unspecified sources (generally including small- to medium-sized private organizations); the other is when the corporation bears the entire cost of dredging. The first method is based on a law which determines the share between public and private organizations. In this case the river control agencies or Administrator will perform the dredging. In the second method, the private organization will perform the project under the guidance of the river control agencies or Administrator. This is based upon the so-called "Law Concerning Entrepreneurs Bearing of the Cost of Public Pollution Control Works," which was enacted in 1970 (Law 133, Dec. 25, 1970). The system is shown in Table 4. Figure 2 shows the amount of sediments dredged and their costs since 1958.

The budget and the number of projects increased year by year. In the fiscal year 1973 over one million cubic meters of sediment were dredged. After the fiscal year 1974 public works projects decreased because the oil crisis caused budget restrictions coupled with a steep rise in prices. Table 5 lists six rivers where projects performed by the river control agency had a total private cost-sharing of 12 million Yen.

The dredging projects which were performed entirely by private organizations are shown in Table 6. These projects were related to dredging of sludge and sediment which included toxic pollutants such as mercury and PCB. The total amount of dredged material was about 140,000 m³, and the expenditures were about 10 million Yen.

TABLE 1. IMPROVEMENT OF WATER QUALITY BY DILUTION

Clean Dilution Water	River to be Purified	Name of City	Max. Water Intake	Start of Construction
(Under Direct Control)				
The Tone River	The Sumida River	Tokyo	30 m ³ /sec.	1964
The Kino River	The Waka River	Wakayama	8	1963
The Yodo River	The Neyo River	Osaka	20	1968
The Edo River	The Naka River	Tokyo	20	1970
The Kiso River	The Arata River	Gifu	6	1972
The Maruyama River	The Tomaki River	Tomioka	5	1972
The Hii River	The rivers in Matsue city	Matsue	7.2	1972
The Umabuchi River	The Umabuchi River	Hachinohe	10	1973
The Yoshino River	The Shinmachi River	Tokushima	10	1974
The Ohno River	The Ozu River	Oita	4	1976
(Grant-in-Aid)				
The Hino River	The old Kamo River	Yonago	1	1972
Sea	The Waka River	Wakayama	10	1973
The Yodo River	The Higashi Yokobori River	Osaka	natural inflow	1975

TABLE 2. POLLUTION CONTROL PROJECTS FOR RIVERS UNDER DIRECT CONTROL

Year	Budget Items	Name of River	Project	Budget	Government Share
1959	A	Arakawa River (Sumida River)	Iwabuchi Gate	20 x 10 ⁶ Yen	2/3
1960	A	same	same	30	2/3
1961	A	same	same	30	2/3
1962	A	same	same	10	2/3
1963	-	-	-	-	-
1964	B	same	Water Introduction	1,150	2/3
1965	-	-	-	-	-
1966	-	-	-	-	-
1967	C	Yodo River (Neya River)	Water Introduction	320	1/4
1968	C	same	same	1,030	1/4
1969	D	same	same	1,640	1/4
1970	D	Yodo River, Naka River	same	720	1/4, 1/2
1971	D	Naka River + 2 Rivers	Water Introd. & Dredging	723	1/3
1972	D	Naka River + 5 Rivers	same	1,449	1/2
1973	D	Naka River + 10 Rivers	same	1,261	1/2
1974	E	Naka River + 13 Rivers	same	1,339	1/2
1975	E	Naka River + 14 Rivers	same	1,479.2	1/2
1976	E	Naka River + 17 Rivers	same	2,208	1/2

[Remarks] A Pollution Control Budget for Direct Control Rivers
 B Budget for Reconstruction of Direct Control Rivers
 C Budget for Pollution Control Projects for Direct Control Rivers
 D Budget for Urban River Improvement Project for Direct Control Rivers
 E Budget for River Improvement Projects for Direct Control Rivers

TABLE 3. POLLUTION CONTROL WORKS FOR GRANTS-IN-AID RIVERS

Year	Budget Items	Districts	Project	Budget	Government Share
1958	A	Tokyo	Dredging	102 × 10 ⁶ Yen	1/4
1959	A	Tokyo, Osaka	same	188	1/4
1960	A	Tokyo, Osaka	same	188	1/4
1961	A	Tokyo, Osaka	same	264	1/4
1962	A	Tokyo, Osaka	same	264	1/4
1963	A	Tokyo, Osaka	same	264	1/4
1964	A	Tokyo, Osaka	same	264	1/4
1965	A	Tokyo + 2 Districts	same	248	1/4, 1/3
1966	A	Tokyo + 3 Districts		253	1/4, 1/3
1967	A	Tokyo + 4 Districts		269	1/4, 1/3
1968	A	Tokyo + 4 Districts		269	1/4, 1/3
1969	B	Tokyo + 6 Districts		660	1/4, 1/3
1970	B	Tokyo + 9 Districts		630	1/4, 1/3
1971	B	Tokyo + 15 Districts		1,030	1/4, 1/3
1972	B	Tokyo + 24 Districts		1,611	1/2, 1/3
1973	B	Tokyo + 36 Districts	Water Introd. & Dredging	1,762	1/2, 1/3
1974	C	Tokyo + 47 Districts	same	1,926	1/2, 1/3
1975	C	Tokyo + 49 Districts	same	2,049	1/2, 1/3
1976	C	Tokyo + 52 Districts	same	2,426	1/2, 1/3

[Remarks] A Grants-in-Aid for River Pollution Control Expenditure
 B Grants-in-Aid for Urban River Improvement Project
 C Grants-in-Aid for River Improvement Project

TABLE 4. RESPONSIBILITY FOR DREDGING AND DREDGING COSTS

Sediment Sources	Responsibility for Dredging	Responsibility for Expenses
(1) Numerous and unspecified	river control agencies or river Administrator	a) government shares expenses with private organizations or b) sole expenditure by public organization
(2) numerous and unspecified sources + specified private organizations	same as above	c) same as a) or: d) shared by public and private organizations
(3) specified private organizations only	specified private organization	e) sole expenditure by specified private organization

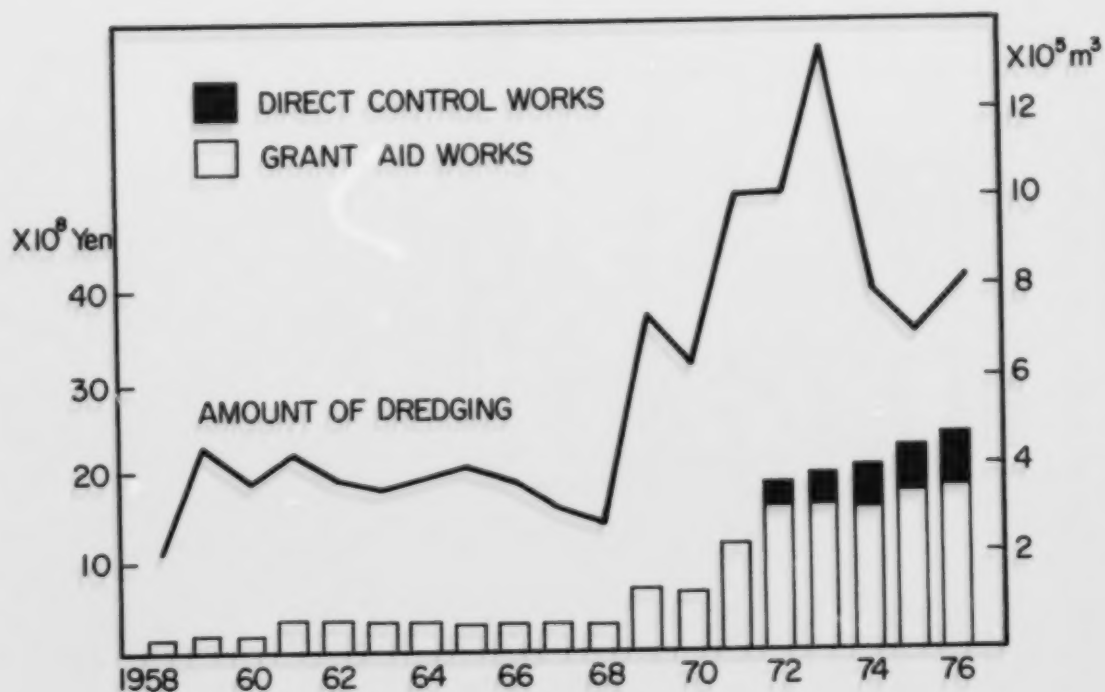


Figure 2. Sludge and sediment dredging projects.

TABLE 5. RIVERS WHERE DREDGING COSTS WERE SHARED WITH PRIVATE ENTERPRISE

	Tagawa River	Tenpaku River	Tsusen River Kurino River	Hama River	Omura River	Iyo-Mishima River
Name of City	Utsunomiya	Yokaichi	Niigata	Nobaoka	Omura	Dredging 10,790 m ³
Project	Dredging 69,770 m ³	Dredging 16,920 m ³	Dredging 234,500 m ³	Improvement of stream channel 2,900 m ³	Dredging 28,000 m ³ Bottom improvement 1,880 m ³	
Total Budget (Yen)	100 x 10 ⁶	143 x 10 ⁶	400 x 10 ⁶	1,284 x 10 ⁶	471 x 10 ⁶	50 x 10 ⁶
Government Share	20.8 x 10 ⁶	15.98 x 10 ⁶	131.804 x 10 ⁶	177 x 10 ⁶	100.51 x 10 ⁶	18.39 x 10 ⁶
Private Share	10.06 x 10 ⁶	12.45 x 10 ⁶	268.196 x 10 ⁶	531 x 10 ⁶	370.49 x 10 ⁶	31.61 x 10 ⁶
Total	30.86 x 10 ⁶	28.43 x 10 ⁶	400 x 10 ⁶	708 x 10 ⁶	471 x 10 ⁶	50 x 10 ⁶

TABLE 6. DREDGING PROJECTS PERFORMED ENTIRELY BY PRIVATE ORGANIZATIONS

River Class	Number of Local Governments and Branches of the Ministry of Construction	No. of Rivers	Amount of Dredged Sediments
Class A River Controlled by Government	4	8	$4.6 \times 10^4 \text{ m}^3$
Class A & B River Controlled by Local Government	9	9	$9.2 \times 10^4 \text{ m}^3$
Total	13	17	$13.8 \times 10^4 \text{ m}^3$

STANDARD FOR ADOPTION OF A RIVER POLLUTION CONTROL PROJECT

Government enforced River Pollution Control Project occurs when a river is "seriously polluted." This classification is applied where:

- Cleanup was already planned when the "River Environmental Standard" was established
- Cleanup is planned as a Pollution Control Project based upon the Basic Law of Environmental Pollution, Sec. 19
- Sediments include excessive amounts of toxic pollutants such as mercury, PBC, etc.
- Water pollution is especially bad (BOD of 10 ppm or more)

SHARED EXPENDITURES FOR RIVER POLLUTION CONTROL PROJECTS

The basic rule states that necessary expenditures for pollution control projects be paid by the person who discharged the pollutants. When the "person" is a specified private organization, it has to perform the dredging by itself under the approval of river control agencies. But in many cases pollution control projects will be done by the river control agencies. This is because the agency may conduct a flood control project concurrent to the pollution control projects. Table 7 lists the government share of such pollution control projects.

OUTLINES OF RIVER POLLUTION CONTROL PROJECTS FOR FISCAL YEAR 1977

The budget for River Pollution Control Projects in fiscal year 1977 is shown in Table 8. Expenditures have increased 121% compared to 1976.

Three channel construction projects for supplying clean water for river purification have been adopted as new direct control projects by the government: the Channel from the Sho River to the Uchi River (Toyama Prefecture), the Channel from the Chikugo River to the Ikemachi River (Fukuoka Pref.) and the Channel from the Oyodo River to the Komatsu River.

New governmental grants-in-aid projects are five dredging projects: the Goya River in the Class A Tone River (Tochigi Pref.), the Takada River in the Class A Yodo River (Shiga Pref.), the Kawahara River in the Class A Hii River (Shimane Pref.) and the Naka River in the Class A Bansho River (Oita Pref.).

LONG-TERM PLANS FOR RIVER POLLUTION CONTROL PROJECTS

Flood control projects began in the fiscal year 1977 as new five-year projects. The total budget necessary for the projects is 7,630 billion Yen (\$35 billion). In these five-year projects river pollution control is one of the most important programs. The essential elements of the plans are as follows:

- a) Promotion of river pollution control projects aimed at an improvement of the river environment
- b) Construction and improvement of sewage facilities in river basins
- c) Enforcement of regulations regarding waste water quality
- d) Promotion of the projects which have been planned under the "Pollution Control Plan" to achieve the defined "Environmental Standard" in certain areas

One of the long-term projects is to perform sediment dredging during the early stages and to later construct canals for purification purposes. For example, about $50 \times 10^6 \text{ m}^3$ of sludge and sediment have accumulated in the whole country and about fifty rivers exist which can easily be cleaned up by building channels to bring in clean water to help with purification.

The first project of the "Pollution Control Plan" started in December, 1970 and, since then, seven projects have been underway. The amount of sediments dredged in the projects is shown in Table 9. The total amount of accumulated sediments is about $12 \times 10^6 \text{ m}^3$, and the total dredged amount up to the fiscal year 1976 is about $1.8 \times 10^6 \text{ m}^3$. The percentage of total material to be dredged is only 15% so far.

DISCUSSION OF RIVER POLLUTION CONTROL PROJECTS

CONFLICT OF NEEDS FOR FUTURE WATER RESOURCES

To move excess water from a large river with high water quality and abundant streamflow into a small river with low water quality and small streamflow is a common practice to purify the smaller river. Usually various facilities (such as dams) will be constructed in the upper reaches of the larger river to facilitate responses to downstream water demands. Equalization of the streamflow will result and the number of possible days of excess water supply

TABLE 9. SLUDGE AND SEDIMENT DREDGED UNDER THE POLLUTION CONTROL PLAN

Project	Start Date	Target Year	Required Dredging Volume	Dredged Volume until 1975	Dredged Volume in 1976	10 ³ m ³ per cent completed by 1976	Place
1st Project	Dec 1, 1970	1975	20.5	20.5	---	100%	Chiba, Ichihara, Yokaichi, Mizushima
2nd Project	Dec 12, 1970	1975 or 1981	7,480	1,190	170	18.2%	Tokyo, Kanagawa, Osaka, Saitama, Arakawa, Chiba, the basin of the Edo River, Kyoto, Nara, the basin of the Yamoto River
3rd Project	Dec 19, 1972	1976 or 1981	2,340	210	40	10.7%	Kashima, Nagoya, Eastern part of Hyogo, Oita, Kita-Kyushu
4th Project	Dec 18, 1973	1977 or 1981	270	14	5	7.0%	Fuji, Southern part of Harima, Otake, Iwakuni, Omuta
5th Project	Dec 27, 1974	1978	650	70	40	16.9%	Tomakomai, Sendai Bay, Iwaki, Chiba seaside, Toyama, Takaoka, Kinugawa, Nishi Mikawa, Kobe
6th Project	Feb 17, 1976	1979 or 1981	520	30	30	11.5%	Bigo, Shunan, Nanyo Muroran, Hachinohe, Niigata, Shizuoka Shimizu, Kyoto, Okayama, Bizen, Wakayama, Ube, Onoda, Shimonoseki, Hiroshima, Kure, Takamatsu, Sakaide
7th Project	Jan 29, 1977	1980	770	--	150	19.5%	Sapporo, Akita, Hitachi, Matsumoto, Suwa, Gifu, Ogaki, Tohno, Eastern Mikawa, Tokushima, Hyuga, Nobeoka
Total			12,050.5	1,345.5	435	14.8%	

will gradually decrease. Consequently there will have to be an adjustment between the amount of water currently introduced and that of potential developed water resources.

CONSERVATION OF DISPOSAL SITES FOR DREDGED SLUDGE AND SEDIMENT

The cost break-down for dredging is shown in Table 10. The cost will depend highly on the conditions of the disposal site. Table 11 shows disposal sites for dredged spoil in the fiscal year 1975. About half of the dredged material is reclaimed in containment areas located at the ports. Recently locating suitable disposal sites has become very difficult, and, the cost of disposal areas for reclaimed sediment has risen year by year. For example, in Tokyo Bay most of the dredge materials became reclaimed land masses. The disposal fee (shown in Table 12) has more than doubled in recent years.

The offshore construction projects at Haneda, where dredged sludge and sediment are now being disposed, will be finished in fiscal year 1977. After completion, a waste treatment site outside the central breakwater is scheduled to be built as a new disposal site. But, in Tokyo Bay, every year has seen the number of available sites reduced and it has become difficult to construct large areas of reclaimed land. Consequently, long term plans are necessary to provide future disposal sites.

MEASURES TO PREVENT ENVIRONMENTAL IMPACTS

Measures should be taken to prevent secondary environmental impacts of odor, noise, vibration, and so forth which result from the processes of dredging, treatment, transportation and disposal. The measures taken to date include:

- a) Water quality monitoring in and around the area of dredging and disposal
- b) Selecting a work schedule which minimizes conflict with fishing and recreational activities
- c) Redesign of construction machinery such as grab buckets and suction dredges
- d) Pollution control in dredging including use of sheet pile cofferdams, sand bags, sheet protection, oil booms, etc.
- e) Design of transport machinery such as improved dump trucks
- f) Treatment of sediments by using chemicals such as coagulants or solidifiers, dewatering sediments by using dewatering machines, sand filters, or sand beds, and by covering disposal sites with asphalt, grass or other plant materials

TABLE 10. BREAKDOWN OF CONSTRUCTION EXPENDITURES

	Direct Control Projects	Grants-in-Aid Projects	Remarks
Dredging	30.6%	31.5%	Sludge transportation costs are included in the case of pump dredger
Treatment	3.7%	7.9%	
Construction of Disposal Site	35.5%	24.7%	Costs of covering disposal site are included.
Disposal Fee	22.8%	8.6%	
Miscellaneous	0.1%	18.3%	Including seawall basement
Total	100.0%	100.0%	

TABLE 11. DISPOSAL SITE

Disposal Site	Direct Control Projects	Grants-in-Aid Projects	Total	Remarks
River Bed	2	10	12	Planning area in park, school, etc. Forest, field, etc. With or without fee
Public Land	2	7	9	
Private Land	-	11	11	
Reclaimed Land	3	26	29	
Total	7	55	62	

TABLE 12. PORTION OF DREDGED DISPOSAL FEES PAID TO THE TOKYO METROPOLITAN GOVERNMENT

Fiscal Year	1972	1973	1974	1975	1976	1977
Unit Share Fee (Yen/m ³)	280	310	310	470	470	780
Percentage of Share Against Total Cost	26%	27%	25%	34%	35%	45%

EXAMPLES OF RIVER POLLUTION CONTROL PROJECTS

THE SUMIDA RIVER

Water Quality

The Sumida River has been a main transportation route for centuries. The history of the Sumida River is closely tied to that of the Tokyo metropolitan area.

The River was the main stream of the Arakawa River until completion of the Arakawa flood control channel in 1930. The water quality of the river was good; there was abundant streamflow and the river supported a fishery and summer recreational activities. About the end of Taisho era in 1925 industrial development and an increase in population caused the water quality to deteriorate rapidly except during the period just after the war.

The worst water quality in the river occurred in 1964. Since then, many water pollution control projects have reversed this downward trend (see Figure 3). These projects include introduction of clean water from the Tone River, construction of sewage facilities, enforcement of effluent limitations and dredging of polluted sludge and sediments.

In 1975 the BOD value in the summer fell to 8 ppm or less in all places except the Odai Bridge. But another index of organic pollution, the COD value, remained high. At the Ryogoku Bridge COD was 9.3 ppm compared to 4.9 ppm BOD, and COD was 11.7 ppm compared to 6.3 ppm BOD at the Shirohige Bridge, i.e., COD was approximately twice that of BOD. This phenomenon will be observed in any river into which various chemicals are discharged or which has a slow flow rate or in which a large amount of sewage has generated non-oxidable substances such as nitrite, sulfite and miscellaneous organic materials not included in BOD. For this type of river it is not always enough to assess organic pollution by BOD value alone.

Outline of Dredging in the Sumida River

Studies (1,2) indicate that some BOD may be due to substances which originate in sludge and sediment. If the elution rate of BOD substances is proportional to the amount of sediment BOD, the removal of sediments may be effective in river cleanup. From this point of view, the Tokyo Metropolitan Government has dredged in the Sumida River since 1958.

DREDGING OF LAKE KASUMIGAURA

Lake Kasumigaura is located at the southeastern end of the Kanto Plains. It has about 220 square kilometers of surface area and a shoreline of about 250 kilometers. The lake is the second largest in Japan (next to Lake Biwa) with a maximum water depth of seven meters and an average depth of four meters. Two projects are currently being conducted—one is a levee project for flood prevention and the other is a water resource development project to cope with increasing demand for water in metropolitan areas.

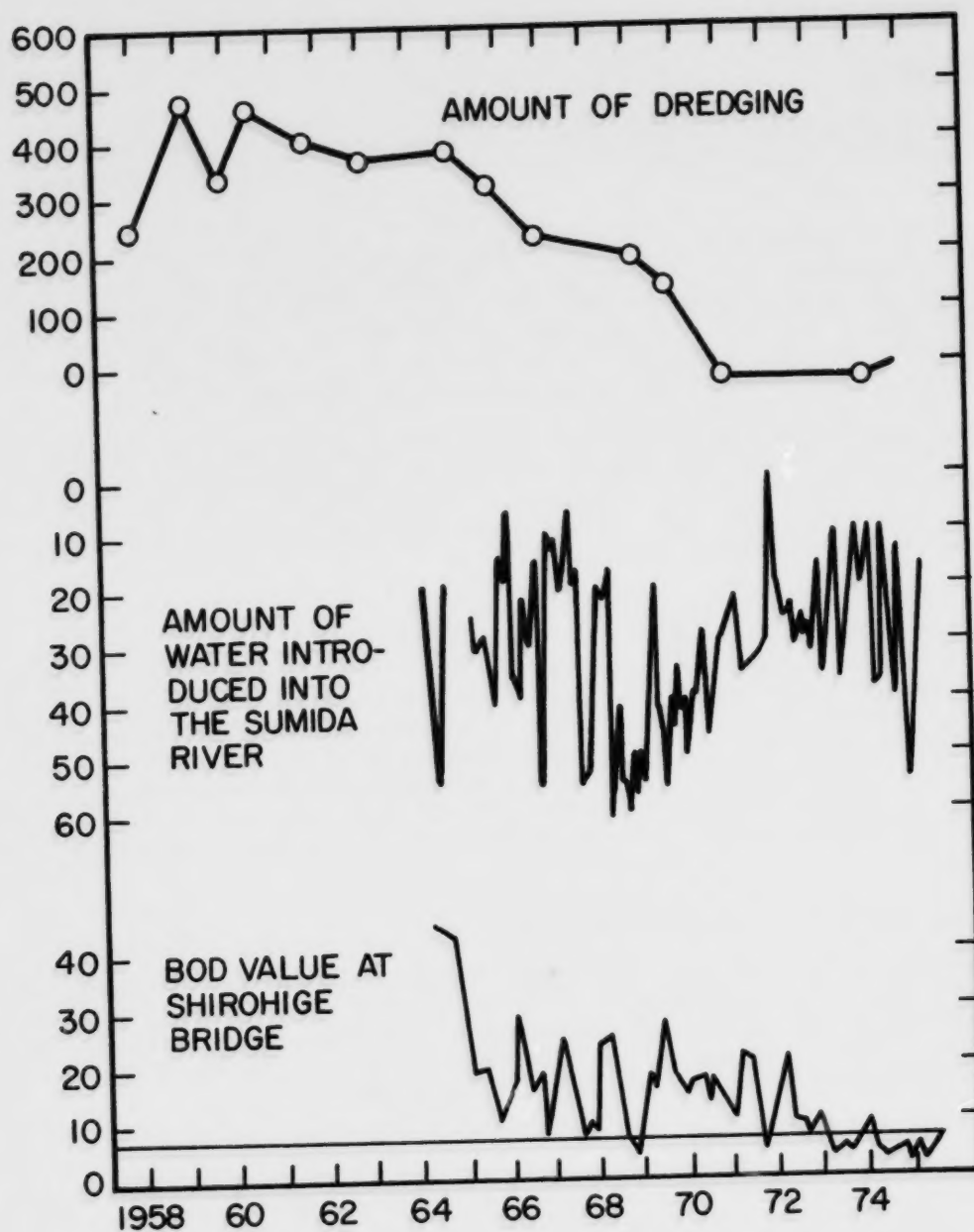


Figure 3. Water quality, amount of dredging and amount of clean water introduced for purification of the Sumida River.

The lake's water quality has recently deteriorated (Figure 4). In 1972 the Environmental Standard for Lake Kasumigaura was set at Classification A-CC (COD 3 ppm or less), the interim classification was B (COD 5 ppm or less). Pollution sources for the lake are domestic, industrial and livestock wastewater plus a relatively large amount of pollutants from bottom sediments generated by the lake itself. To clean up the lake the Ministry of Construction surveyed the sediments and authorized the dredging of $1.2 \times 10^6 \text{ m}^3$ of sediments. About 300,000 m^3 of sediments are planned to be dredged by 1982.

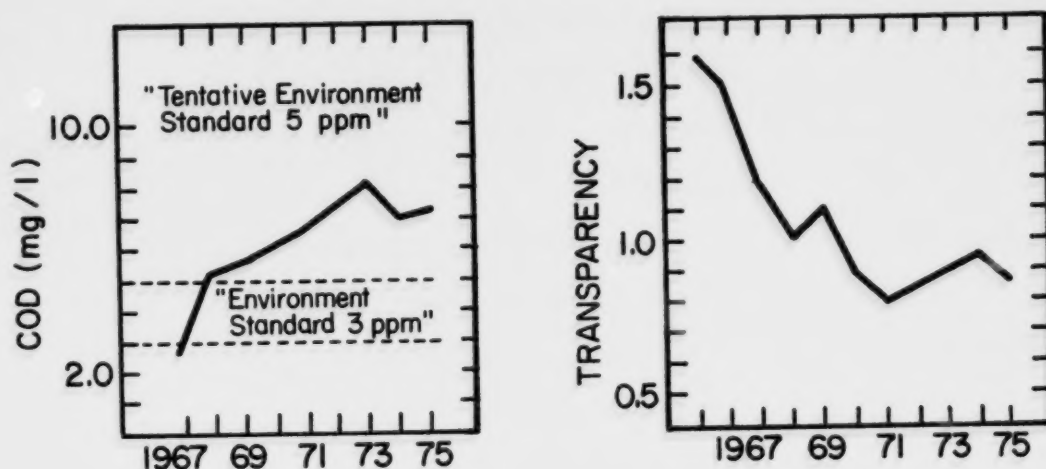


Figure 4. Water quality variation at Lake Kasumigaura.

A large amount of water for agricultural and urban use is drawn from Lake Kasumigaura, but the lake is also used for fishing and recreation. Thus, there are many factors to be considered in dredging and attention should be paid to possible sources of secondary pollution.

The dredge Kasumi-Go was developed especially with this in mind. It is practical from standpoints of both economics and pollution control. The dredge's specifications are shown in Figure 5.

Special features are:

- a) no generation of secondary pollution while dredging
- b) feasibility of collecting large amounts of sludge and sediment
- c) no special disposal areas required
- d) no treatment required for discharged effluents

Dredging Capacity:	Dredging Depth	5 m below water surface
	Rated Capacity	60 m ³ /hr
	Working Distance	30 - 150 m

Sludge Sampling Equipment:

Capacity	0.5 m ³ × 2 units
Diameter of delivery pipe;	105 mm
Type of Valve:	bevel valve/ball valve

Generator:	230 PS < 1,800 rpm
	180 KVA

Vacuum pump:	Capacity: 7 m ³ /min × 7 kg/cm ²
	Motor: 15 KW × 440 V

Compressor:	Capacity: 72 m ³ /min × 7 kg/cm ²
	Motor: 55 KW

Winch:	Three Drum Type × 2 units
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Intake & Delivery Pump:	0.36 m ³ /min., 0.22 m ³ /min
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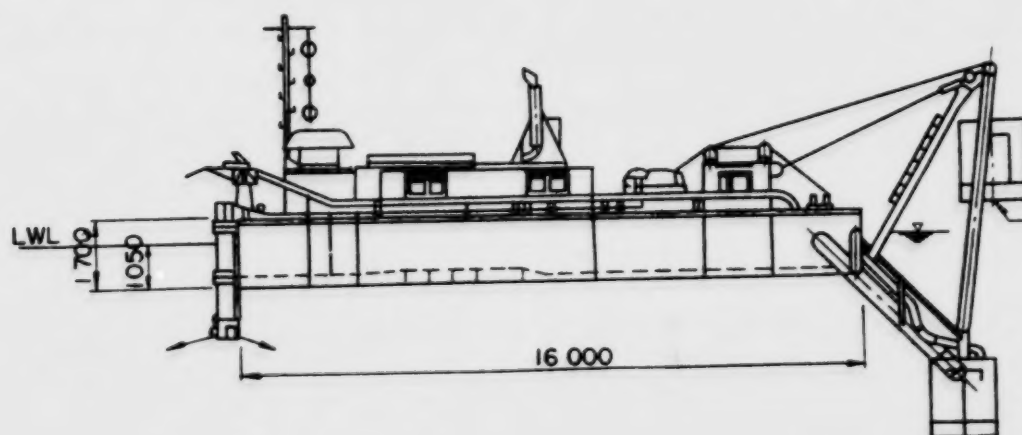


Figure 5. Outlines and specifications of sludge dredger, Kasumi-Go.

Various studies and tests on reuse of spoils dredged have been conducted for land reclamation or for bank filling.

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TURBIDITY GENERATED BY DREDGING PROJECTS

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SUMMARY

This paper discusses investigations into turbidity generated by dredging during port construction. The study was made by the Bureau of Ports and Harbors and the Port and Harbor Research Institute, Ministry of Transport from 1973 to 1976.

Field investigations were conducted to develop a method for predicting the quantity of turbidity generated by various dredges in different kinds of soil. A turbidity generation unit (TGU) was calculated using the results of these field investigations. It is defined as the quantity of turbidity generated per unit volume of dredged material, and can be effectively used to predict the quantity of turbidity.

INTRODUCTION

Marine transportation in the coastal areas of Japan has been common for centuries. There are currently more than one thousand ports and new port construction projects are still going on. This work affects the marine environment and can cause serious problems.

The coastal areas have also been used as fishing grounds since ancient times. The turbidity generated by current port construction, although limited in space and time, is confined to specific areas of which ten are fertile fishing grounds.

The impact of turbidity on the fishery is usually negative because turbidity may cause the following undesirable phenomena:

- (1) Decreases of photosynthesis in phytoplankton due to decreased transparency
- (2) Interference with fish feeding on benthos
- (3) Interference with respiration of fish
- (4) Decreased habitat area for fish
- (5) Negative effects on esthetic quality because of the muddy water

In addition to these problems, toxic substances may be released from the dredged sediments along with the turbidity.

To deal with these problems, the Bureau of Ports and Harbors and the Port and Harbor Research Institute, Ministry of Transport, conducted field investigations from 1973 to 1976 to determine the quantity and diffusion characteristics of turbidity generated by various types of dredges in several kinds of soil.

These investigations do not study the problem of soil contaminated with toxic substances. This is addressed in a Tentative Guideline for Managing Contaminated Bottom Sediments which was promulgated by the Environmental Agency in 1974. Part of the solution was to use special cutterless pump dredges developed to lessen the quantity of turbidity generated. Canvas shrouds are also set around the dredge to localize the turbidity. The Tentative Guideline also points out the importance of monitoring water quality and fish during the dredging period.

INVESTIGATION OF TURBIDITY GENERATED BY DREDGING

CONCEPT OF THE TURBIDITY GENERATION UNIT

The mechanism of generating turbidity by dredging is different for each type of dredge. The diffusion of suspended material is influenced by tidal current, grain sizes and other soil conditions as well as the irregularities in the dredge action and bottom configuration. Figure 1 shows a schematic of the process of turbidity generation.

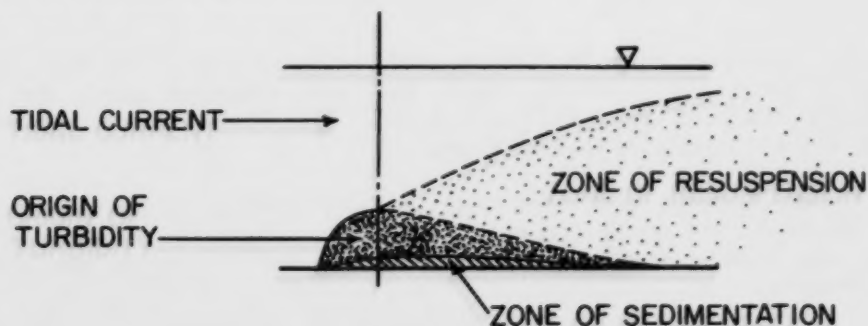


Figure 1. Generation mechanism of turbidity.

In this paper turbidity is defined as the mass of suspended solids. The quantity of turbidity is assumed to be proportional to the quantity of dredged materials. Therefore:

$$W_o = CW_s \quad (1)$$

where,

- W_o = total quantity of turbidity generated by dredging works (ton)
- C = a coefficient dependent on dredge type, soil condition, etc.
- W_s = total quantity of dredged materials (ton)

To simplify the process of estimating turbidity, the concept of a turbidity generation unit (TGU) was introduced. This stands for the quantity of turbidity generated when a unit quantity of bed material is dredged under a standardized condition. The method of standardizing the TGU is as follows:

A standard tidal current velocity is determined by the condition that soil particles with diameters larger than 74μ (silt) are not resuspended. This leads to the relation:

$$W = K \cdot W_o / Q_s = K \cdot C \cdot \gamma \quad (2)$$

where,

- W = turbidity generation unit (ton/m^3)
- Q_s = volume of dredged materials (m^3)
- γ = specific weight of dredged materials (ton/m^3)
- $K = R_{74}/R_o$
- R_{74} = fraction of particles with a diameter smaller than 74μ
- R_o = fraction of particles with a diameter smaller than the diameter of a particle whose critical resuspension velocity equals the current velocity in the field.
- W_o, C = as in equation (1)

Critical resuspension velocity is defined as the minimum current velocity under which a specific particle is not resuspended. The relationship between particle diameter and critical resuspension velocity depends upon Ingersol's or Camp's equation. Table 1 gives some of those relationships as derived from these equations.

TABLE 1. RELATIONSHIP BETWEEN DIAMETER OF SOIL PARTICLE AND CRITICAL RESUSPENSION VELOCITY

Classification of Soil	Particle Size (mm)	Critical Resuspension Velocity (cm/sec)	Equation used for Derivation
clay	~ 0.005	~ 0.03	Ingersol
silt	$0.005 \sim 0.074$	$0.03 \sim 7$	Ingersol
fine sand	$0.074 \sim 0.42$	$7 \sim 15$	Camp et al.
rough sand	$0.42 \sim 2.0$	$15 \sim 35$	Camp et al.

When the tidal current velocity in the field, V_{co} , is given, W can be calculated using the following procedure:

- (1) the diameter of particle d_0 , which has a critical resuspension velocity V_{co} , is determined from the lower curve in Figure 2.
- (2) R_0 is also determined from Figure 2 using the upper curve of cumulative particle size for sediments in the field.
- (3) W_0 and Q_s are gained from field investigation and W is then calculated according to equation (1).

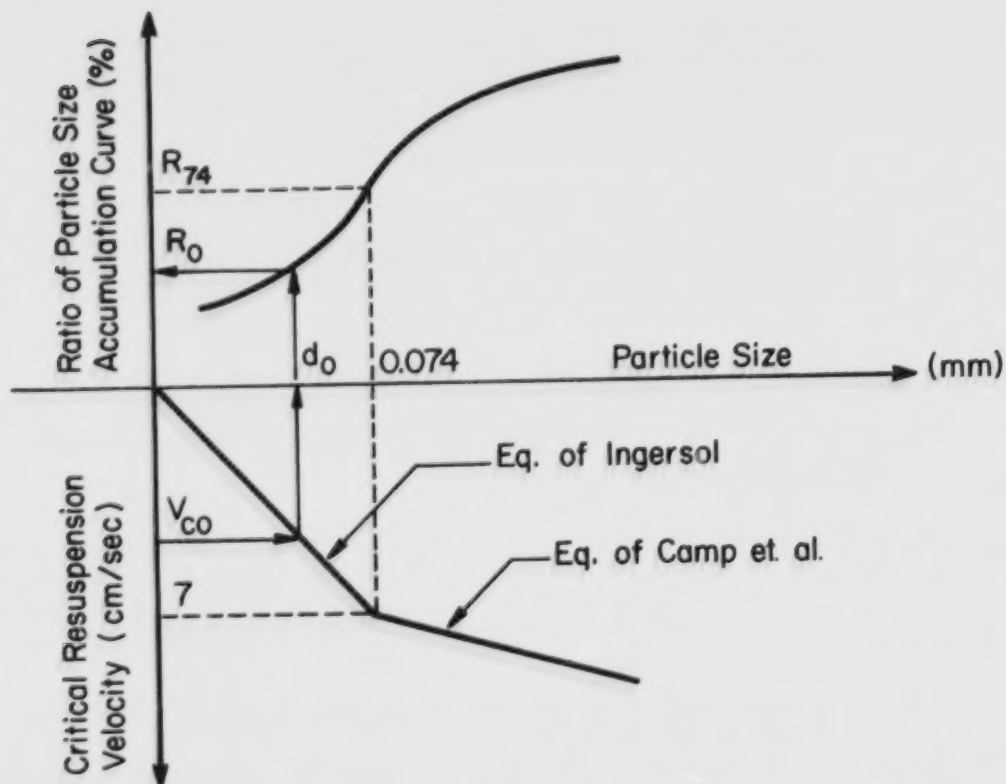


Figure 2. Method of standardization of turbidity generation unit.

FIELD INVESTIGATION METHODOLOGIES

To determine the TGU, many field investigations were made at many ports. The following methodology was developed after much experience.

(1) Water Sampling Stations

Water sampling stations should be arranged in straight lines orthogonal to the direction of the tidal current but taking into consideration the velocity of the tidal current and the area of dredging. Figure 3 shows an example of the arrangement of stations. The lines are arranged for the following purposes:

- line I ----- to measure the background turbidity value
- line II ----- to measure the generated turbidity and check the coefficient of diffusion
- line III ----- to check the quantity of turbidity measured at line II and to check the coefficient of diffusion

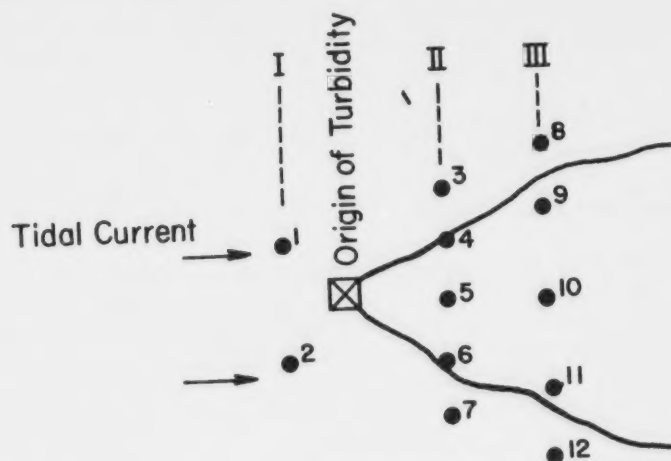


Figure 3. Arrangement of turbidity measuring stations.

The vertical arrangement of water sampling stations depends on the water depth. When the water depth is approximately 10 meters, three water levels should be sampled. Figure 4 shows an example of the vertical arrangement.

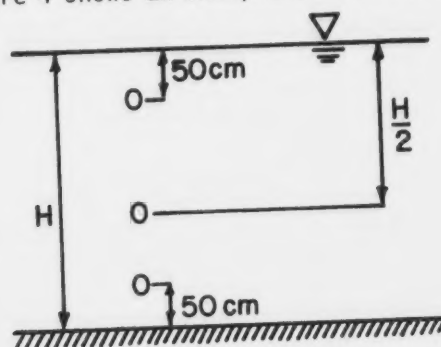


Figure 4. Vertical arrangement of sampling points.

Since the direction and the velocity of the tidal currents are very important factors, preliminary investigation should be done to determine them before the dredging begins. This is necessary to find out whether or not

turbidity generated by the dredge will be detected at the selected sampling stations.

(2) Water Sampling

The mass of suspended solids in the water samples is measured to estimate the turbidity generation unit. Each water sample should be taken simultaneously at all points and at short intervals during the dredging. Though the interval of water sampling is often restricted by working conditions, there should be at least one hour of continuous sampling at 10 minute intervals. If possible, it is best to calculate the quantity of turbidity by integrating continuously measured values.

(3) The particle size distribution of the bottom sediment must be measured prior to dredging operation.

(4) Tidal Current and Water Depth

The direction and the speed of the tidal current are important factors in estimating the turbidity generation unit and they should be carefully measured. Better results can be obtained from a large number of samples so measurements should be made at two or more points for each of the three depth layers. Since water depth changes gradually due to the tide, it should be measured simultaneously with each water sample.

(5) Aerial Photographs

Aerial photography can be used to calculate the coefficient of diffusion and obtain the diffusion pattern. Photographs should be taken simultaneously with the water samples.

(6) Volume of Dredged Materials

Measurement of the volume of dredged materials is the most important factor in estimating the turbidity generation unit. The method is different for each type of dredge. For example, with a pump dredge, volume can be obtained by measuring both the soil concentration and volume of interstitial water.

(7) Position of Dredge

In dredging using pump dredges or bucket dredges the position of the turbidity source changes every moment and therefore, the position should be recorded with respect to time.

METHOD OF ANALYSIS

There are many methods for estimating the quantity of turbidity generated by a dredge from measured data. Two typical methods are discussed—the water sample method and the use of aerial photographs.

(1) Calculating the quantity of turbidity passing through a line of water sampling points is the method used in this paper. Figure 5 shows an

example of the arrangement of water sampling sites in a field investigation.

This is the method used in this paper. The total quantity of turbidity can be calculated as follows:

The net concentration of suspended solids (SS) generated by dredging, S , is defined as:

$$S = S' - S_0 \quad (3)$$

where,

S = net concentration of SS generated by dredging
 S' = concentration of SS measured in the field during dredging
 S_0 = background concentration of SS

The total quantity of turbidity generated by dredging W_0 can then be calculated using the formula:

$$W_0 = \Sigma A \cdot U \cdot S \quad (4)$$

where,

W_0 = total quantity of turbidity (mass of suspended solids) generated by dredging
 A = area of section concerned
 U = tidal current velocity
 S = net concentration of SS measured in the field during dredging

(2) Measuring the width of turbid water using aerial photographs.

The width of the turbid water area taken by aerial photographs only shows the surface layer. If the width of the turbid water area is assumed to be nearly equal from surface to bottom, the total quantity of turbidity, W_0 , can be calculated by the relation:

$$W_0 = B \cdot H \cdot U \cdot S \quad (5)$$

where,

W_0 = total quantity of turbidity (mass of suspended solids) generated by dredging
 B = width of the turbid water area as measured by the aerial photographs
 H = depth of water
 U = tidal current velocity
 S = net concentration of SS generated by dredging

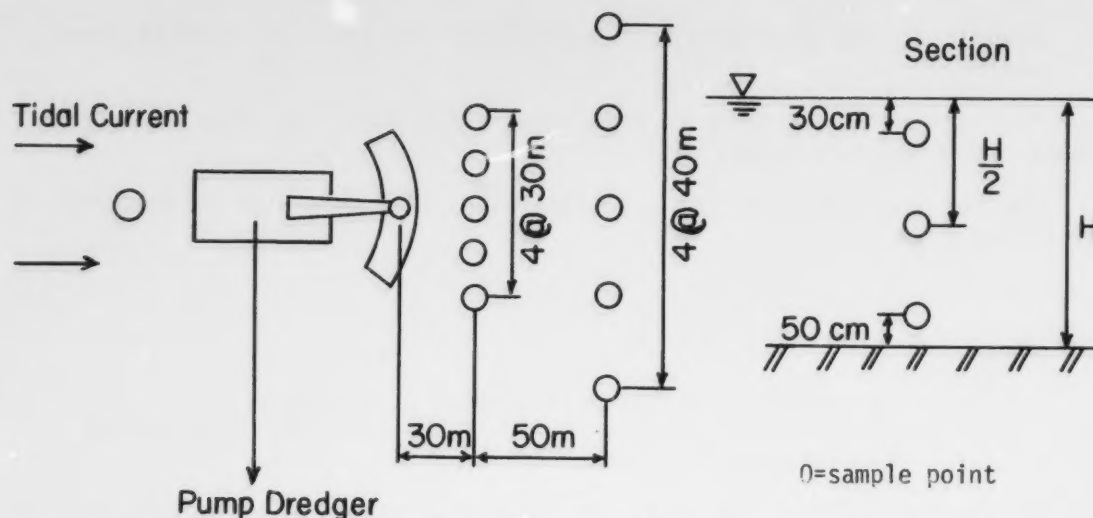


Figure 5. An example of a field arrangement for water sampling.

RESULTS AND CONCLUSIONS

Table 2 shows the results of investigations using method (1) which calculates the turbidity from water samples passing through a line of points. Turbidity generation units in Table 2 are normalized to the standard velocity of about 7 cm/sec (see Figure 2). Dredge type, horsepower or bucket volume and dredged material classification are factors affecting the magnitude of the generation unit. But, judging from Table 2, the horsepower or bucket volume does not seem to be as significant a factor as the other two. Turbidity generation units are therefore discussed only in relation to the type of the dredge and the kind of material dredged.

The following general characteristics of the TGU can be concluded from Table 2.

- 1) The TGU varies with different dredged materials. For example, the TGU for a pump dredge is in the vicinity of 40 kg/m³ for clay but only around 0.2 kg/m³ for sand. For a grab dredge, the TGU is about 84 kg/m³ for clay and around 15 kg/m³ for silty loam. In general, the smaller the particle size, the larger the TGU.
- 2) There are enough data to compare the TGUs for clay among the three types of dredges: the pump dredge, grab dredge and trailing-suction dredge. The TGU value of 25 kg/m³ is the smallest for the trailing-suction dredge. The other values are 35 kg/m³ for the pump dredge and 84 kg/m³ for the grab dredge.

Turbidity generated by several dumping projects was investigated in addition to the studies on dredge-generated turbidity. The TGUs for dumping are calculated using the same method as for dredging. Some of the results are shown in Table 3.

TABLE 2. TURBIDITY GENERATION UNITS FOR DIFFERENT DREDGES AND DREDGING PROJECTS

Type of Dredge	Power or Bucket Volume	Dredged Materials			Turbidity Generation Unit kg/m ³
		d* < 74 μ	d* < 5 μ	Classification**	
pump	4,000 HP	99.0 %	40.0 %	silty clay	5.3
		98.5	36.0	silty clay	22.5
		99.0	47.5	clay	36.4
		31.8	11.4	sandy loam	1.4
		69.2	35.4	clay	45.2
		74.5	50.5	sandy loam	12.1
	2,500 HP	94.4	34.5	silty clay	9.9
	2,000 HP	3.0	3.0	sand	0.2
		2.5	1.5	sand	0.3
		8.0	2.0	sand	0.1
trailing-suction	2,400 HP × 2	92.0	20.7	silty clay loam	7.1
		88.1	19.4	silty loam	12.1
	1,800 HP	83.2	33.4	silt	25.2
grab	8 m ³	58.0	34.6	silty clay	89.0
	4 m ³	54.8	41.2	clay	84.2
	3 m ³	45.0	3.5	silty loam	15.8
		62.0	5.5	silty loam	11.9
		87.5	6.0	silty loam	17.1
bucket		10.2	1.5	sand	17.6
		27.7	12.5	sandy loam	55.8

* d is the diameter of soil particles

** classification is according to the triangular soil classification system

TABLE 3. TURBIDITY GENERATION UNITS FOR DUMPING PROJECTS

Type of Dredge	Barge Volume or Generating Power	Dumped Materials			Generation Unit kg/m ³
		d <74 μ	d <5 μ	Classification	
Barge	500 m ³	36.5 %	13.0 %	silty loam	14.9
		21.5	10.0	silty loam	15.8
		20.5	15.0	silty clay loam	10.6
	180 m ³	2.7	----	sand	0.02
		57.7	27.5	silty clay loam	8.3
	120 m ³	22.7	----	sandy loam	3.8
		19.1	6.8	sandy loam	143.5
Trailing	2,400 HP	68.6	19.4	silty loam	22.7
Suction	1,800 HP	82.2	33.4	clay	123.4

THE RELATIONSHIP BETWEEN GENERATED TURBIDITY AND DREDGE OPERATING FACTORS

The work discussed in the previous section was performed under standardized dredge operating conditions. In the field, the conditions which influence dredge operation are quite variable. The influence of these factors on the generation of turbidity must be known in order to apply this analysis to actual field projects. In this section, the relationship between turbidity and dredging operating factors for the pump dredge and grab dredge are discussed.

PUMP DREDGE

On the pump dredge the studies were made with the dredge operating factors shown in Table 4.

TABLE 4. PUMP DREDGING OPERATING FACTORS

Test No.	Cutter's Revolutions Per Minute	Swing Speed (m/min.)	Thickness of Dredged layer
C ₁	18	6	large *
C ₂	18	8	large
C ₃	18	10	large
C ₄	18	6	small **
C ₅	18	8	small
C ₆	18	10	small
C ₇	0	6	small

* "large" means about 1.5 m in thickness

** "small" means about 0.8 m in thickness

Following are the results of tests made under these seven conditions.

(1) Dredging capacity

Dredging capacity seems to depend upon average dredging thickness, $\bar{t}_s$, and average swing speed, $\bar{V}_s$, so $\bar{t}_s \cdot \bar{V}_s$ is given as a parameter for estimating dredging capacity.

As shown in Figure 6, the concentration of dredged materials, $\bar{x}$, is nearly proportional to $\bar{t}_s \cdot \bar{V}_s$. The relationship between them can be described according to the formula:

$$\bar{x} = 45.5 (\bar{t}_s \cdot \bar{V}_s / D_c \cdot V_{s0}) \quad (6)$$

where,

- $\bar{x}$ = concentration of dredged materials (%)
- D_c = maximum diameter of cutter (cm)
- V_{s0} = standard swing speed (= 8 cm/sec.)
- $\bar{t}_s$ = average dredging thickness (m)
- $\bar{V}_s$ = average swing speed (m/min)

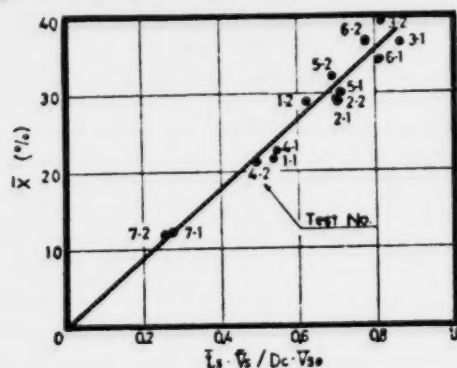


Figure 6. Relationship between pump dredge operating factors and concentration.

(2) Distribution of turbidity

To analyze turbidity generation the distribution of turbidity around the cutter head of the pump dredge was obtained as shown in Figure 7. Points A and B show sampling points on both sides of the cutter. Turbidity is greater at point A than at point B. This difference seems to be related to the revolution of cutterhead.

Figure 8 shows the vertical distribution of turbidity. From this figure it is clear that turbidity is higher in the lower layer (10 m below the surface) than in the upper layer (0.5 m below the surface). In comparing the differences according to dredging thickness, the thicker the cut, the more turbidity is generated.

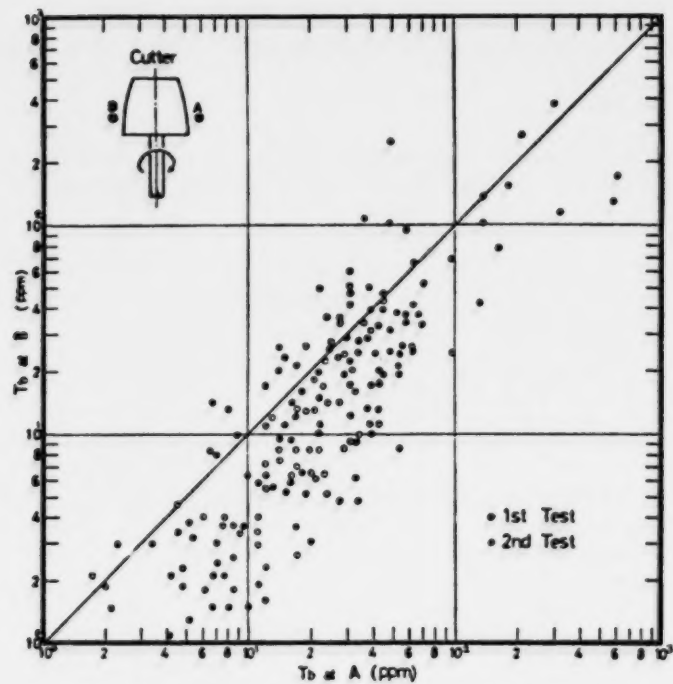


Figure 7. Turbidity around cutterhead.

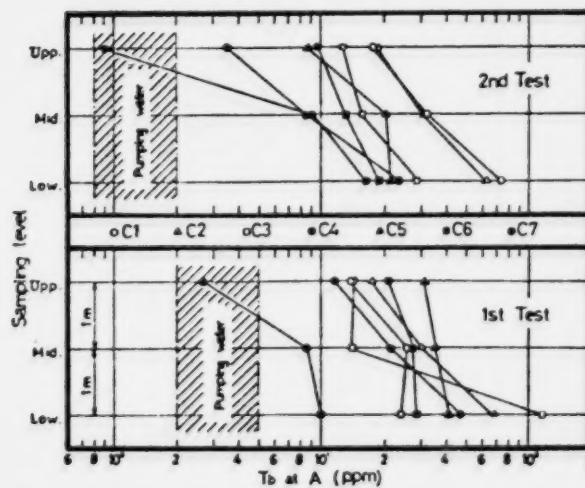


Figure 8. Vertical distribution of turbidity around cutterhead (C1 to C3: thickness $\sim 1-5$ m C4 to C7: thickness ~ 8 m).

(3) Relationship between turbidity and dredging operating factors for the pump dredge

The quantity of materials dredged can be calculated from the moving distance of the dredge, depth of cut, and swing speed. If dredged materials are all taken in through the suction head, the concentration of dredged materials, X_c , in the delivery pipe is given as:

$$X_c = l_a \cdot t_s^a \cdot V_s \cdot / 15\pi D^2 V \quad (7)$$

where,

l_a = arching distance of head for one swing (m)
 t_s^a = depth of cut for one swing (m)
 D = diameter of delivery pipe (m)
 V = swing speed (m/min.)
 V_s = flow velocity in delivery pipe (m/sec.)

In reality not all of the dredged materials are taken in through the suction head. Some remain at the dredge site and some are suspended in the water. If we use X as the actual measured concentration of dredged materials in the delivery pipe, then the effective sucking ratio is expressed as X/X_c and R , the ratio of non-sucked soil to total soil dredged, is defined as:

$$R = 1 - \frac{X}{X_c} \quad (8)$$

and the cumulative ratio of soil, R' , is defined as

$$R' = 1 - \frac{\sum X}{\sum X_c} \quad (9)$$

Figure 9 shows the relationship between R' and the concentration of suspended solids. Figure 10 shows the relationship between R' and V_s/V_{so} .

Using these curves we can derive the best dredge operating factors to use with a given soil concentration to control turbidity. For example, if the concentration of suspended solids is to be less than 100 mg/l, suitable dredging conditions and the value for the concentration of dredged materials can be calculated as follows.

From Figure 9 the value of R' must be in the range 0.15 ~ 0.20. Using this result with the curve in Figure 10 leads to the requirement that the value of V_s/V_{so} should be 1.2 ~ 1.4. When t_s/D is set at 0.58 ~ 0.59 the concentration of dredged materials, x , is 31 ~ 36 % as determined by equation (6). These are then the required operating factors:

net dredging thickness (m)	6.4 ~ 6.5
dredging thickness per swing (m)	1.60 ~ 1.63
swing speed (m/min.)	9.6 ~ 11.2
concentration of dredged materials (%)	31 ~ 36

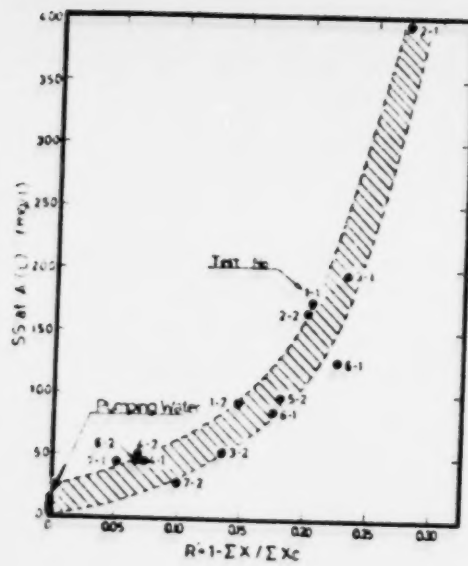


Figure 9. Relationship between R' and concentration of SS.

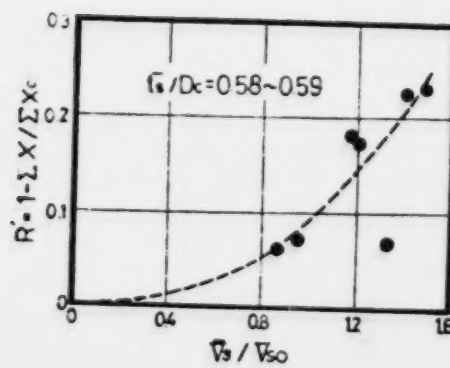


Figure 10. Relationship between swing speed and R'

GRAB DREDGE

For the grab dredge similar calculations were made using the dredge operating factors in Table 5.

This study showed that the turbidity generated by a grab dredge depends upon a parameter, P , where $P = (\text{weight of grabbed materials per cycle}) \times (\text{hoisting speed})$. Figure 11 and Figure 12 show the relationship between maximum turbidity and P , and between average turbidity and P , respectively. These figures imply that there is an optimum value of P which will minimize the turbidity generation.

TABLE 5. DREDGE OPERATING FACTORS

Test No.	Hoisting Speed (m/sec.)	Dredging Thickness
C ₁	1.29	large *
C ₂	1.29	small **
C ₃	0.83	large
C ₄	0.83	small

* "large" means that the entire volume of the grab bucket is filled.

** "small" means that half the volume of the grab bucket is filled.

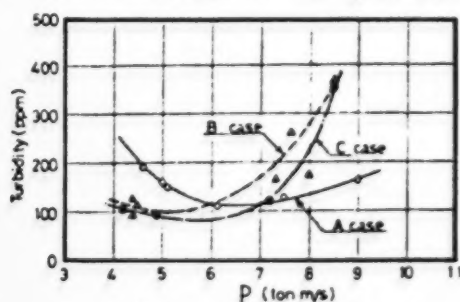


Figure 11. Maximum turbidity vs. P .

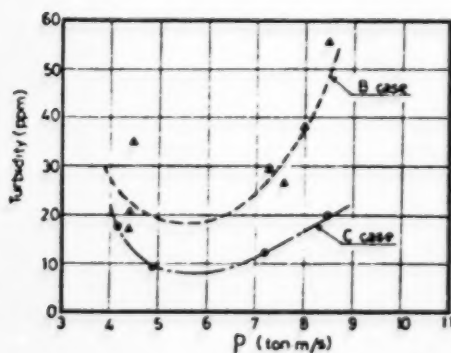


Figure 12. Average turbidity vs. P .

APPLICATION OF THE RESULTS

The results of these investigations are applicable in the following situations.

- (1) Application to environmental impact assessment of construction projects.

The change in concentration of turbidity around a construction site can be predicted using the turbidity generation unit as input data in a simulation model of diffusion.

- (2) Design of a water quality monitoring system for use during construction projects.

The TGU and the relationship between dredge operating factors and turbidity are useful in deciding where to place monitoring points, and what the required measuring range of the apparatus should be.

- (3) Determination of optimum dredging operating factors

These investigations show that there is an optimum set of dredge operating factors which minimize the turbidity generation.

REFERENCES

1. The 4th District Port Construction Bureau, Ministry of Transport. Investigation of the influence of turbidity caused by dredging works. 1976.
2. Yokuji Yagi *et al.* Influence of Operating Condition against Dredging Capacity and Turbidity. Technical Note of Port and Harbor Research Institute. No. 228 Sept. 1975.

APPENDIX I

SUSPENDED SOLIDS (SS)

Suspended solids are those substances which can be separated by filtration or by means of a centrifugal separator. SS is defined as the concentration of suspended solids in water and is commonly used as an index of the turbidity level of water. There are quantitative methods of measuring SS, and the Japanese Industrial Standard (JIS) prescribes the following two methods:

1. Filtration Method

This method determines the suspended solids by filtering the water sample and weighing the filtrate. There are two kinds of filtration methods - the Sintered Glass Filter Method and the Büchner Funnel Method.

SS can be obtained from the following formula:

$$S = (a - b) \cdot 1,000/V \quad (A1)$$

where,

- S = suspended solid concentration (mg/l)
- a = difference in weight of the test water before and after filtration (mg)
- b = difference in weight of the filtrate before and after filtration (mg)
- V = volume of test water (ml)

2. Centrifuge Method

This method separates suspended solids from the test water under centrifugal force. It is primarily used with water samples containing very fine suspended solids.

Concentration of suspended solids can be obtained by following formula:

$$S = a \cdot 1,000/V \quad (A2)$$

where,

- S = concentration of suspended solids (mg/l)
- a = difference in weight of the test water before and after centrifugation (mg)
- V = volume of test water (ml)

APPENDIX II

TURBIDITY

The Japanese Industrial Standards (JIS) prescribe methods for measuring turbidity where a unit of turbidity of 1 ppm is defined as the level of turbidity of 1 liter of water containing 1 mg refined Kaoline.

1. General Method

This simply compares the sample by eye with a series of standard solutions containing refined Kaoline.

2. Photoelectric Photometer Methods

There are two methods which use a Photoelectric photometer. One measures the percent of 660 mμ light passing through the sample, and the other measures the light scattered by the small particles contained in the water sample.

RECENT PROGRESS IN TECHNIQUES FOR MANAGING CONTAMINATED BOTTOM SEDIMENTS

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SUMMARY

This paper provides a brief introduction to recent progress on management techniques for contaminated bottom sediments. It includes comments on the Technical Guideline prepared by the Japan Dredging and Reclamation Engineering Association (hereafter referred to as the JDREA).

INTRODUCTION

In Japan many ports, rivers, lakes and marshes possess contaminated bottom sediments which create undesirable effects on the surrounding environment. The pollutants in these bottom sediments are traced to waste from manufacturing plants or mine tailings (such as in Tagonoura Port or Minamata Bay), urban sewage, agricultural effluents and other industrial or urban sources.

The most effective solution to the problem is to control pollution at the original source, but this is usually very difficult or impractical. Therefore, the management of contaminated bottom sediments has to be implemented in conjunction with countermeasures taken directly at the sources. Thanks to strict enforcement of legal restrictions on effluents at their origin it is likely that accumulation of contaminated sediments will decrease in the future.

Meanwhile, some extreme cases of bottom pollution must be dealt with immediately. The increased level of management in Japan has encouraged development of new techniques in this field. To establish new criteria the JDREA has been engaged, under the sponsorship of the Japanese Government, in the formulation of a Technical Guideline on continual management of bottom sediments. In the following sections the current status of the management techniques are presented. Many of the updated techniques were developed as stated in our review of the Guideline during the 1976 conference.

PLANNING TECHNIQUES

REMOVAL CRITERIA

The government has set tentative criteria for sediments contaminated with mercury and PCB. In the case of mercury, any contaminated deposits exceeding a

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density of 25 ppm mercury in rivers or marshes are subject to removal. In marine areas removal standards have to take into account certain marine phenomena and other related factors before the final decision for removal is made. A more precise method is needed for comparing sea waters with rivers. Table 1 shows examples of Government-set standards for mercury which led to removal projects in certain areas. They serve as useful references for setting up new criteria in the future.

TABLE 1. EXAMPLES OF CRITERIA FOR REMOVAL OF MERCURY-CONTAMINATED SEDIMENTS

Area	Criterion (Mercury-ppm)
Tokuyama Bay	> 15
Minimata Bay	> 25
Dohkai Bay	> 30
Mizushima Port	> 36

The same areas in Table 1 have a standard for PCB which specifies that deposits contaminated with over 10 ppm PCB (per weight of dried sediment) must be removed.

No toxic substances other than mercury and PCB are covered by the official tentative standard.

Dominant pollutants in Japan are not always limited to these two substances and consequently other standards are needed for other toxic materials. Because of increased interest in bottom-sediment management the impetus for a new standard has increased, and the JDREA has responded with the Technical Guideline presented in this paper.

The JDREA's Technical Guideline classifies contaminated bottom sediments into three types: toxic substances, organic sediment, and oily sediments.

Toxic Sediments

Some toxic substances are specifically identified in the Technical Guideline (Table 2). The sediments are considered toxic when the solute concentration in a solubility test is greater than the indicated value. According to an interim Government manual, the condition designated in Table 2 is necessary but not sufficient for justifying removal. It is needed to establish a removal situation but an individual technical judgment is also required.

Some local governments have their own standards which are more detailed than those of the national government. Table 3 lists the standards set in Yokohama City.

TABLE 2. CRITERIA FOR JUDGING TOXIC SEDIMENTS

Toxic Pollutant	Measured Concentration from the Solubility Test
	detectable only
Alkyl mercury	0.005 mg/l
Mercury	0.1 mg/l
Cadmium	1.0 mg/l
Lead	1.0 mg/l
Organic phosphorus	0.5 mg/l
Hexivalent chromium	0.5 mg/l
Arsenic	1.0 mg/l
Cyanide	0.003 mg/l
PCB	

TABLE 3. EXAMPLES OF CRITERIA FOR REMOVAL OF TOXIC SEDIMENTS AT YOKOHAMA

Soil Type	Toxic substance (ppm)					
	Cyanide	Total Mercury	Cadmium	Lead	Chromium	Arsenic
Sandy	1.2	1.2	24	240	24	6
Silt, clay	2	2	4	40	40	10
Organic	3	3	6	60	60	15

Organic Sediments

Sediments with a significant amount of ignition loss* are defined as organic sediments, according to the JDREA's Technical Guideline. Sediments polluted with organics have a negative influence on the environment in three ways:

- (1) They reduce oxygen concentrations which threaten the life of fish and shellfish.
- (2) Phosphorus and nitrogen are released which causes eutrophication.
- (3) Hydrogen sulfide is released under anaerobic conditions causing odors and other problems. No official criteria has been set with regard to organic sediments.

In the meantime, local port management agencies are attempting to set up their own removal criteria to cope with the organic pollution of sediments. The Technical Guideline lists these local criteria as a reference. One example is given in Table 4 for Nagoya Port management agency. If any two of the three criteria are met, then the sediments should be dredged and disposed.

* low fraction of ash-free dry weight.

TABLE 4. CRITERIA FOR REMOVAL OF ORGANIC SEDIMENTS AT NAGOYA PORT

Item	Standard
Loss on ignition	over 10%
COD	over 20 mg/g
Sulfide	over 1 mg/g

Oily Sediments

The accumulation of sediment contaminated with oil is a major problem. Oil-contaminated fish have a bad odor which is usually caused by mineral oils. But sediments contaminated with organically-derived oils may be dangerous enough to kill fish and shellfish if they are highly concentrated. Oily sediments might well be classified with the organic sediments (see above). Taking this point of view, the Technical Guideline classifies sediments with a high density of normal hexane extractions as oily sediments.

For the time being, establishment of removal criteria for oily sediments is left to the technical judgment of the parties concerned. Since there is much less data available as management examples for oily sediments, the Technical Guideline contains only the two actual cases given in Table 5. There is still room for improvement of these techniques.

TABLE 5. EXAMPLES OF REMOVAL CRITERIA FOR OIL SEDIMENTS

Water Area	Criteria for Removal (Density of normal hexane extractions)
Mizushima Port	2,000 ppm
Yokkaichi Port	4,000 ppm
Yokkaichi Port	2,000 ppm (mineral oils)

Incidentally, the Japan Marine Resources Protection Association is of the opinion that the standard density of normal hexane extractions should be reduced to below 1,000 ppm.

SECONDARY POLLUTION CAUSED BY REMOVAL AND DISPOSAL OPERATIONS

The management work may sometimes temporarily increase turbidity. It is important to prevent this, especially if the sediments are toxic. It requires the latest techniques to be able to judge to what extent temporary turbidity caused by such operations must be controlled.

The criteria for monitoring water quality during the management operations are decided by the Government. Table 6 is the official standard for toxic substances in water.

Table 7 contains general criteria applicable to water quality during management operations where special consideration is given to the seafood

products industry. These criteria have more severe standards, depending on particular conditions. Therefore, any technical judgment will actually depend on the parties concerned.

Various reference data are inserted in the Technical Guideine for the purpose of formulating criteria applicable to water quality during management operations. For instance, the influence of suspended solids on fish and shellfish are stated in Table 8 and the correlation between oil concentration in sea water and occurrence of malodorous fish is given in Table 9.

TABLE 6. CRITERIA FOR MONITORING WATER QUALITY DURING DREDGING AND DISPOSAL (PART 1)

Toxic Substance	Standard
Cadmium	less than 0.01 ppm
Cyanides	not detectable
Organic phosphorus	not detectable
Lead	less than 0.1 ppm
Hexivalent chromium	less than 0.05 ppm
Arsenic	less than 0.05 ppm
Total mercury	less than 0.0005 ppm
Alkyl mercury	not detectable
PCB	not detectable

TABLE 7. CRITERIA FOR MONITORING WATER QUALITY DURING DREDGING AND DISPOSAL (PART 2)

Water Quality	Standard
pH	7.0 - 8.3
COD	less than 8 ppm
DO	over 2 ppm

TABLE 8. EFFECTS OF SUSPENDED SOLIDS ON FISH AND SHELLFISH

Fish and Shellfish	Suspended Solids (ppm)	Observation
Prawn	over 50	existence hampered
Immature yellowtail	over 20	existence hampered
Red sea bream	over 100	flutter frantically
Pearl oyster	over 7	water absorption changed

TABLE 9. EXPOSURE TIME AND OIL CONCENTRATION CAUSING FISH FLESH ODOR PROBLEMS

Oil	Fish	Hours exposed	Oil concentration
Light oil	Saurel	2 hours	0.43 ppm
		24 hours	0.043 ppm

DREDGING TECHNIQUES

GENERAL DESCRIPTION

The Government is now administering the dredging of accumulated sediments. According to official requirements an ocean area is divided into two sections; one is the minimum operative area within which temporary turbidity due to dredging is unavoidable, the other is the area which must be protected from the dredging operations. Thus, attention must be paid to water quality along the boundary line so turbid water does not enter the side to be kept clean. Techniques for dredging bottom sediments have been developed which place primary emphasis on minimizing turbidity while still maintaining dredging efficiency. A secondary emphasis has been to dredge all materials in a given area and to have dredged material contain a high concentration of solids.

The technical developments on these approaches are touched on in the Technical Guideline, but further research is strongly advised, since many difficult problems are left unsolved.

CLASSIFICATION OF DREDGING TECHNIQUES

Advanced dredging techniques have been tailored to dredging specific bottom sediments. The Technical Guideline shows 32 dredges, each equipped with special devices for specific sediments. These are shown in Table 10.

PUMP DREDGES

Dredges in groups A, B and C in Table 10 use pumps. Hopper dredges in group A have suction heads suitable for dredging contaminated sediment. Few examples of the performance of this type of dredge are recorded.

Groups B and C have similar features since most are operated by the sideways-swing movement of the suction head. In their operation the volume of turbidity produced as well as the dredging efficiency is governed by the swing speed and the depth of cut on each swing. This means that increased swing speed and greater depth of cut will result in more turbidity being generated, but that the efficiency of removing the sediment (in terms of dredge production) will also increase.

TABLE 10. CLASSIFICATION OF DREDGES EQUIPPED WITH SPECIAL DEVICES SUITED TO DREDGING FOR CONTAMINATED SEDIMENT

Group	Dredging Technique	Number of Vessels
A	Hopper dredge	5
B	Cutter suction dredge	1
C-1	Cutterless suction dredge	Centrifugal pump type
C-2		Pneumatic pump type
C-3		Piston pump type
C-4		Other pump types*
D	Grab dredge	3

* peristaltic and screw pumps

Turbidity is aggravated by cutters, so the cutter suction dredges in group B generate heavier turbidity than the cutterless type dredges in group C. The Technical Guideline presents data (Tokuji Yagi *et al.*) showing operating conditions of a cutter suction head in order to maintain turbidity concentrations, close to the cutter, of approximately 100 mg/l. The above example is only one case and is not applicable where dredge types and sediment characteristics are different. However, it may still illustrate the general relationship between operating conditions of cutter suction heads and the suspended solids caused by their operation. The concentration in Table 11 is the percentage of solids contained in the total discharge passing through the sump, and the sediment volume in the calculation is that of the *in situ* state prior to the dredging.

TABLE 11. OPERATING CONDITIONS OF SUCTION DREDGES WITH CUTTER HEAD (regulated SS: 100 mg/l)

Item	Operating Condition
Swing speed	9.6 - 11.2 m/min
Dredged thickness per swing	1.6 m
Concentration of solids in slurry	31 - 36%

Cutterless suction dredges can minimize the occurrence of this type of turbidity by utilizing various type pumps, by reducing the hydraulic gradient around the suction head or by fitting special devices to the suction head. As with cutter suction dredges, the occurrence of turbidity and the dredging

efficiency of cutterless dredges is regulated by the swing speed and the depth of sediment cut. For example, with clayey sediments, turbidity will be sharply increased when the swing speed reaches a certain level.

The Technical Guideline suggests the standard operating conditions as stated in Table 12 are appropriate for maintenance of the surrounding water quality within allowable limits.

TABLE 12. STANDARD OPERATING CONDITIONS FOR CUTTERLESS SUCTION DREDGES

Item	Operating Condition for clayey sediments
Swing speed	less than 5m/min
Depth of sediment cut	0.3 - 1.0 m (depending on sediments and water quality)
Depth of sediment cut (final dredging)	sometimes less than 0.1 m
Concentration	less than 30% (average of the total)

"Final dredging" is a process required where all the existing sediments are to be completely dredged.

Suction dredges (with or without cutters) generally suck a considerable volume of water with the dredged material. However, some cutterless dredges are able to exclude water fairly well if specialized methods are employed. Such dredging methods are not highly efficient and inevitably suck a huge volume of water in the "finishing-up" stages. The average concentration reported in Table 12 is low for this reason. Under some conditions it may be that more attention should be given to treating a small amount of in-place sediment after dredging rather than attempting to remove every last bit of the sediment. Organic sediments are an example of this situation. Dredging at a high spoils density by raising the mud content is therefore recommended at the expense of operating efficiency. This question will be raised again in connection with the transportation of contaminated sediments.

Table 10 refers to only one cutter dredge since it is the only one equipped with special devices for contaminated sediment dredging. In contrast to Table 10, Table 11 refers to cutter section dredges without special devices.

GRAB DREDGES

Two of the three grab dredges listed in group D of Table 10 are equipped with special closed grab buckets designed to prevent leakage of sediments. These specialized devices are not necessary where turbidity diffusion is controlled by confinement to narrow channels or by some other method of enclosure. In these situations conventional dredges have been used. Grab dredges are most suitable where a higher soil content of the dredged spoils is desired.

VOLUME OF SEDIMENT SUSPENDED BY DREDGE OPERATIONS

Most of the sediment contacted by a dredging head is removed, but some portion escapes and remains undredged, and some is suspended in the water. The suspended and diffused sediments are called "suspensoids." Estimating the volume of suspensoids is difficult. Some observers feel that the volume is proportional to the total dredged volume. The author and Technical Guideline support this concept. Table 13 presents a rough estimate for the amount of sediments suspended per cubic meter of dredged material.

TABLE 13. GENERAL RANGE OF SUSPENDED SOILS

Mode of dredging	Suspended Soils (metric ton/m ³)
Cutter suction dredge	5 - 50 × 10 ⁻³
Cutterless suction dredge	0.5 - 5 × 10 ⁻³

Suspensoids will be diffused due to tidal currents. Since tidal currents are complicated it is difficult to evaluate how strongly the resuspended sediments will affect surrounding water quality.

MEASURES TO PREVENT DIFFUSION OF SUSPENSIDS

To control diffusion of suspensoids, enclosing booms (silt curtains) are often employed to encircle the dredge. The many types of materials that have been rapidly put on the market for this purpose attest to the efficacy of this technique. Booms are made of non-percolated polypropylene, polyethylene, foamed styrole and percolated synthetic fibers. To support them, various types of floats are used. In our Technical Guideline, three typical products are given for reference among the many products in this line.

TRANSPORTATION TECHNIQUES

TRANSPORTATION VIA PIPELINE

In the case of cutterless suction dredges, pumps suck highly concentrated sediments and then transport them through pipelines. Some grab dredges also use pumps and pipelines. The discharge distance is dependent upon the concentration of the dredged spoils. With a higher density, the distance that the spoils can be pumped becomes shorter (see Table 14).

The discharge distance of a cutterless suction dredge may be increased considerably by lowering the concentration of solids in the slurry. This is shown in Table 15.

A booster pump can be employed for long-distance transportation through pipelines, except when the dredged sediments must be highly concentrated.

TABLE 14. RELATIONSHIP BETWEEN CONCENTRATION AND DISCHARGE LENGTH

Mode of Dredging	Concentration	Discharge Length	Remarks
Pneumatic pump type cutterless suction dredge	80%	80 m	Oozer pump used
	60%	240 m	
Open-type grab dredge	60%	200 m	Dredged by grab and discharged by pump
	40%	400 m	
	20%	500 m	

TABLE 15. RANGES OF DISCHARGE LENGTH USING MAIN PUMPS OF CUTTERLESS SUCTION DREDGES FOR HIGH AND LOW SPOILS CONCENTRATIONS

Type of Pump	Range of Discharge Length
Centrifugal	500 - 3,500 m
Pneumatic pump	80 - 1,500 m
Piston pump	350 - 600 m
Other special pump	1,000 m

TRANSPORTATION BY BARGE

When highly concentrated dredged materials are to be transported long distances, barge transportation will be connected with the discharge pipeline from a cutterless suction dredge. Two modes of barge systems are described in the Technical Guideline:

- (1) Hopper barge with bottom doors; used only in special cases since there is leakage from the barge bottom
- (2) Hopper barge with a closed bottom; the bottom is closed and a grab or pump is used for the final discharge of spoils

LAND TRANSPORT

Dredged sediments are unloaded onto a spoils site and then transported to a designated disposal area. For this purpose the Technical Guide refers to land transport employing trucks or conveyer belts. Sediments are commonly stocked at disposal areas and solidified by stabilizers such as lime or cement. Liquid sediment is rarely transported by trucks. However, the exact degree of solidification required for land transport has not been decided.

OCEAN DISPOSAL OF DREDGED SPOILS

SPOILS SITES

It is a common practice to confine dredge spoils and convert them to a non-toxic state. Usually a site on land is necessary, but if the volume to be disposed is large, nearshore ocean disposal can be better utilized for a reclamation site. Bulkheads are used to confine dredged sediments which are sometimes sealed by an overlay of clean soil.

Since coastal areas are already very developed, a minimum space for the confinement of dredged materials should be determined and secured in advance. Development of a theoretical calculation for the space required is still in progress. Empirically derived estimates are now employed.

Some data obtained from actual examples in several places are presented in the Technical Guideline as shown in Table 16.

TABLE 16. EXPANSION OF DREDGED SEDIMENTS AND VOLUME OF RECLAIMED LAND

Port	Ratio of Volume of Reclaimed Land to Volume of Dredged Materials	Sediment Expansion Ratio
Iwakuni	1.35	1.22
Ohmuta	1.90	1.23
Shimonoseki	2.14	1.51
Tokuyama & Kudamatsu	2.28	1.60
Tokuyama & Kudamatsu	3.24	1.60
Yokkaichi	3.47	1.28

The sediment expansion ratio refers to the volume of the dredged materials just after confinement as compared to that of the bottom deposit before dredging. The wide variance in the above table demonstrates the technical difficulties involved in theoretically determining fill volumes. The causes of these difficulties are attributable to the following points:

- (1) Sediment volumes are expanding owing to dilution by sea water. This is an extremely variable property of sediment.
- (2) It takes a long time for fine particles to precipitate out from seawater. Since turbid seawater must be accumulated in the reclamation site, a calculation to determine the area required for dumping is very difficult.

WASTE WATER TREATMENT

The sediments dumped into the fill area replace an equal volume of sea water. Most suction dredges generally discharge a large volume of water along

with sediments. The sea water is contaminated by contact and must be treated or released in its contaminated state. The following methods for purifying sea water are given in the Technical Guideline.

Utilization of Large Land Areas

When a relatively large area of reclaimed land is available, pollutants can be eliminated through natural sedimentation, after which the purified water can be released into the open sea. This is the simplest wastewater treatment. The process may be accelerated by using earth banks within the reclaimed area to elongate the stream. Agglutinants can also help promote sedimentation.

Utilizing a Settling Basin

A part of the reclaimed land area is partitioned into a settling basin. Contaminated sea water leads to the spillway passing through the basin where pollutants may settle out. Agglutinants may be added at the inlet of the basin and the deposited pollutants are occasionally removed to maintain depth in the basin. The index of suspended solids removed by sedimentation using this basin is shown in Table 17.

TABLE 17. PERCENT SS REMOVED IN THE SEDIMENTATION BASIN

Port	SS Density of In-flow Water	SS Density of Out-flow Water	% SS Removed
Shimonoseki	25 - 50 ppm	13 - 16 ppm	48.0 - 68.1%
Dohkai Bay	5,000 - 15,000 ppm	180 - 250 ppm	95.0 - 98.8%

Utilization of a Filter Bed

This method is the most efficient form of wastewater management. A filter bed is installed at a point higher than sea level. Sea water confined in the reclaimed land is guided into the filter bed, which can reduce the suspended solids to less than 15 mg/l.

There are two types of filter—a simple type made of sand, which is easily replaced when clogged, and another type consisting of a steel tank in which a filter of sand and anthracite is contained, along with a back washing device. Table 18 shows results of wastewater treatment using such a filter in combination with a settling basin.

SOIL STABILIZATION METHOD

Overlay or soil stabilization is necessary for land reclaimed with sediments because:

- (a) The environment can be adversely affected by dispersion of toxic sediments or release of gas.

TABLE 18. EXAMPLES OF WASTEWATER TREATMENT USING FILTER BEDS

Port	In-flow Water Quality	Out-flow Water Quality	Flow Velocity	Filter
Higashiharima	SS: 150 ppm	SS: 5 ppm PCB: 0.01 ppm	400 m ³ /hour	Sand/anthracite
Yokkaichi	SS: 100 ppm	SS: 10 ppm Oil: 2 ppm	22,000 m ³ /day	Sand/anthracite

- (b) The reclaimed land is strengthened by a soil layer giving it enough bearing power to be of practical use.

When soil is laid for reason (a) it is called overlaying, while for reason (b) it is called soil stabilization. They both amount to the same thing.

The Technical Guideline describes the overlay technique as follows:

(1) Direct method

When the surface of the confined material is relatively solid, uncontaminated soils can be gradually laid from one side of the reclaimed land by bulldozers. However, such conditions are quite rare.

An overlay method with selected light materials, scattered by portable belt conveyers or jet conveyers, is applicable effectively to soft surface conditions. A cone penetration index of 13.6 - 16.4 kg/cm² (life: 28 days) was obtained when a mixture of blast furnace slag with a little cement was used as the overlay material in thickness up to 60 - 80 cm. A bearing power to permit heavy vehicle passage can be derived using this method.

(2) Use of sheets

Overlaying can be done by scattering clean solid materials on the soft mud after setting sheets of nets. Sheets and nets help distribute the loads imposed by the overlayment, and control possible swelling of sediments. One example is given in Table 19.

(3) Stabilization using chemical aids

If lime or cement is spread over the surface material and mixed by earth-moving machines, the surface will become solidified. When at a later time good soils are scattered, a stabilized stratum will be achieved.

In the case where sediments are extremely soft and liquid-like, stabilizers (mostly lime or cement) are applied and mixed by machines mounted on pontoons. As a result, liquid sediments can be virtually solidified at an unconfined compression strength of up to 0.5 - 1.0 mg/cm². Table 20 gives a classification value for several types of solidifying agents.

TABLE 19. OVERLAYING TECHNIQUE USING SHEETS AND NETS

Site	Sediments	Overlayment	Overlaid Area	Sheeting Materials	Overlay Method
Imari	8 m	2.0 m	103,000 m ²	PP sheet, PP rope to be anchored on banks at 20 m intervals	Bulldozer Dump truck
Yokkaichi	6 m	1.5 m	16,500 m ²	Net (synthetic resin) Float (synthetic resin)	Submerged pump Bulldozer Dump truck
Kitakyushu	7 m	1.5 m	52,600 m ²	Bamboo mats at 70 cm intervals, PP sheet, PP rope	Small suction dredge Dump truck Bulldozer

TABLE 20. CLASSIFICATION OF SOLIDIFYING AIDS

Major Ingredient	Classification of Solidifying Aids
Cement	9
Lime	2
Agglutinant	2
Other	4 (Asphalt, Soluble glass, etc.)

LAND DISPOSAL OF DREDGE SPOILS

In some cases usable reclaimed areas were formed by practicing simple drainage, natural drying and overlaying. These examples involved a small volume of less than 10,000 m³ of contaminated mud, dredged in high density by cutterless suction dredges, and then transported to the fill site. More complicated methods may be required depending on sediment characteristics. Sometimes small volumes of sediments, confined and treated, can be used to make a playground or park.

OCEAN DUMPING

Dredged materials are sometimes discharged into the ocean. The regulations strictly prohibit discharge of oily or toxic sediments into the sea. But for organic mud, restrictions are not so severe. Organic sediments will cause some eutrophication in surrounding waters, but this is alleviated by discharging in the open ocean. Table 21 outlines one example in which dredging of a bay was conducted to restore productivity to a fish farm.

TABLE 21. EXAMPLE OF OCEAN DUMPING

Applied sediments	Classification	Organic sediments
	Toxic substances	None
	Oily substances	Mineral oil not found
Condition of dumping spot	Water depth	Over 200 m
	Distance from coast	32 - 35 km
	Distance from dredge site	44 - 47 km
Specification of barges	Type	Self-propelled
	Number of vessels	4
	Gross tonnage	490 metric tons each
	Volume of hold	720 m ³
	Hold cover	Hatch cover
	Wave resistance	Wave height 2.5 m
Discharge Mechanism	Type	Movable discharge pipe along-side
	Pump volume	2,280 m ³ /hour
	Discharge depth	5 m below the surface
Navigation	Speed (open sea)	10 knots
	Speed (inner harbor)	4 knots
	Trip time	6 hours

Although ocean dumping is not always economical, it has the advantage that the natural circulation system will take care of the spoils without subsequent trouble.

CONCLUSION

Management of contaminated bottom sediments has progressed with adoption of better environmental standards. There are still many fundamental problems to be solved. For instance, the problems of what types of contaminated sediments will be removed, how heavily will suspended solids be produced, and how can the

bearing strength of reclaimed land be improved? Since management techniques for contaminated sediments will be required for some time, it is desirable that these fundamental problems be solved as rapidly as possible.

REFERENCE

Tokuija Yagi et al. Influence of operating conditions against dredging capacity and turbidity. Technical Note of the Port and Harbor Research Institute, No. 228, September 1975.

DREDGING TOXIC SEDIMENTS IN YOKKAICHI PORT

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SUMMARY

An outline of Japanese dredging projects to remove contaminated sediments was presented at the Second Conference held in Tokyo in October, 1976. This paper is a followup to report on the actual dredging work taking place in Yokkaichi Port.

INTRODUCTION

Yokkaichi Port is located on the northwest edge of Ise Bay on the Pacific Coast of Japan (Figure 1). It has played a very important role in the development of this region.

In 1952 a petrochemical complex was founded on the outskirts of Yokkaichi Port; by 1953 fish caught in nearby areas were found to smell bad. The fish had been contaminated by oil from the bottom sediments and this caused economic damage to the region's fishing industry.

To clean the port it was necessary to dredge the bottom sediment as well as to regulate industrial waste water and improve sewage disposal facilities. The Port Management Organization took charge of the project. Various measures were taken to prevent secondary pollution before commencing work. These measures are briefly mentioned in this report.

PLAN FORMULATION

The Basic Law for Environmental Pollution Control was enacted in 1967 and Pollution Control Programs were formulated in accordance with this law. In Japan, pollution control measures are comprehensively and systematically applied in areas where pollution is serious or likely to become serious due to rapid increases in population or industrial concentration.

In December 1970, the Mie Prefectural Government formed the Yokkaichi Regional Pollution Control Program and the Yokkaichi Port Authority decided to carry out the dredging. We organized a Cost Allocation Council in Yokkaichi Port and the Council set up subcommittees to investigate the following three subjects:

- (1) Standards for dredging bottom sediments in Yokkaichi Port.

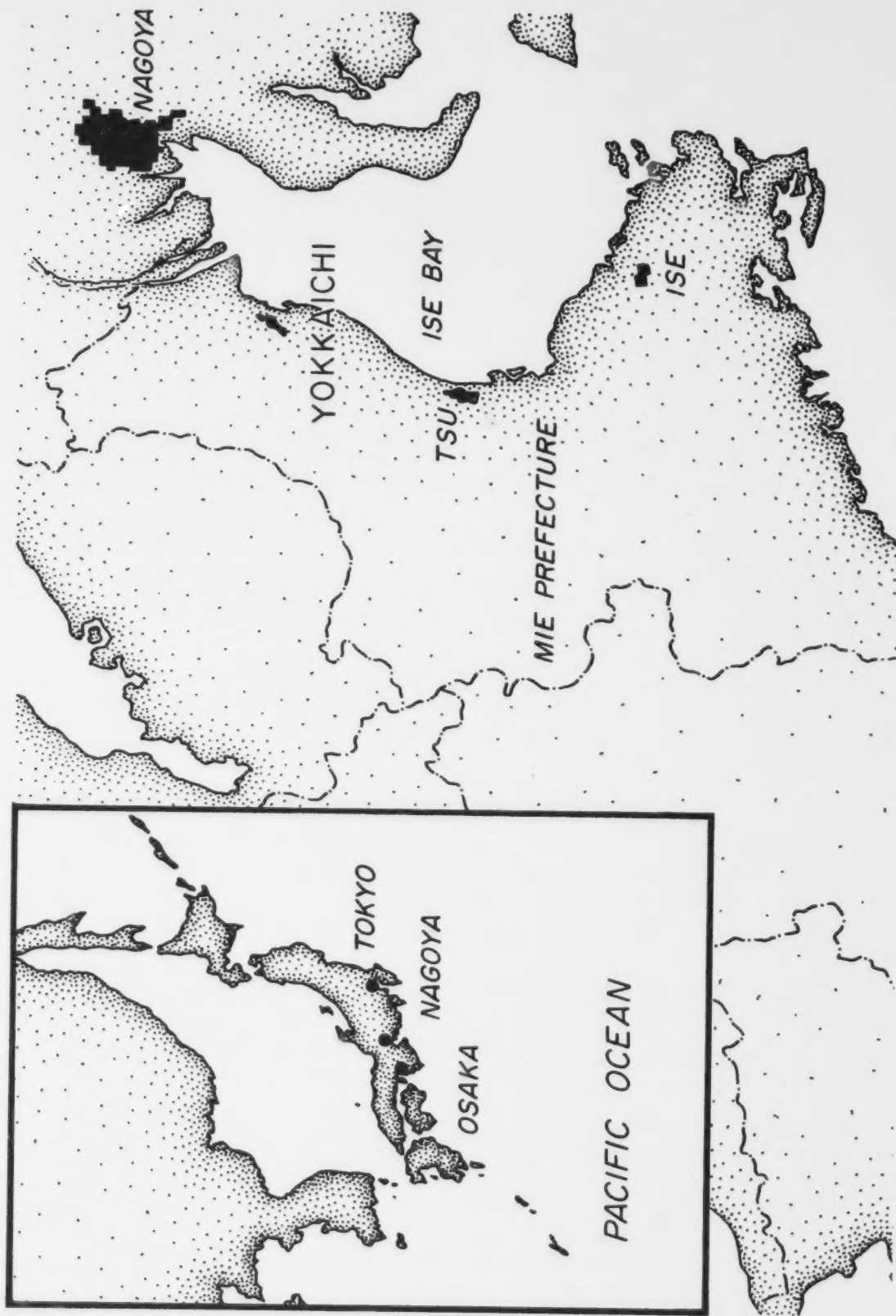


Figure 1. Location.

(2) Methods of dredging and disposing of contaminated sediment.

(3) Basic rules of cost allocation.

Based on the Council's report, the Yokkaichi Port Authority decided to begin a four-year plan in April, 1974. The contents of the report are outlined as follows.

Standards for Dredging Bottom Sediments

Any sediment containing more than 4,000 ppm of a n-Hexane extraction or more than 6 ppm of total Mercury is to be dredged. This criterion covers approximately 2,200,000 m³ out of a total of 2,500,000 m³ of sediment which accumulated in the area investigated. The ocean bottom to be dredged is approximately 1,200,000 m² out of 1,300,000 m² in the area investigated (Figure 2).

Methods of Dredging and Disposing of Contaminated Sediment

Since the sediment to be dredged includes a high content of toxic substances, we are required to use a dredging method which will not cause secondary pollution. Therefore, when selecting dredges it is important to use a type that will not disperse the sediment and the spoils will contain as high a concentration of solids as possible.

The method of disposing of the dredged sediment is to construct a retaining wall so the dredged sediment can eventually be covered with good soil and the area reclaimed for use. Approximately 400,000 m² of the area at the east end of the Kasumigaura reclamation site was selected where reclamation work was already being carried out.

Since the distance from the dredging area to the disposal site is nearly 5 km, the transportation method chosen must consider safety and prevention of noxious odors, as well as economic aspects.

The supernatant water from the dredge spoils is run into a settling pond constructed beside the reclamation pond where it is treated and discharged into the sea. The disposed sediment in the reclamation pond will ultimately be covered with soil.

It is expected that secondary pollution caused by dredging will be prevented by using the above method. To ensure this, water quality and other environmental indicators will be monitored. In the report it is suggested that an Investigation and Judgment Committee be organized to direct the monitoring and to judge the results. There is also a supplementary opinion that some preliminary work should be done before the actual work begins.

Basic Rules of Cost Allocation

Since the basic rules of cost allocation were reported at last year's Conference, we will not repeat this topic here.

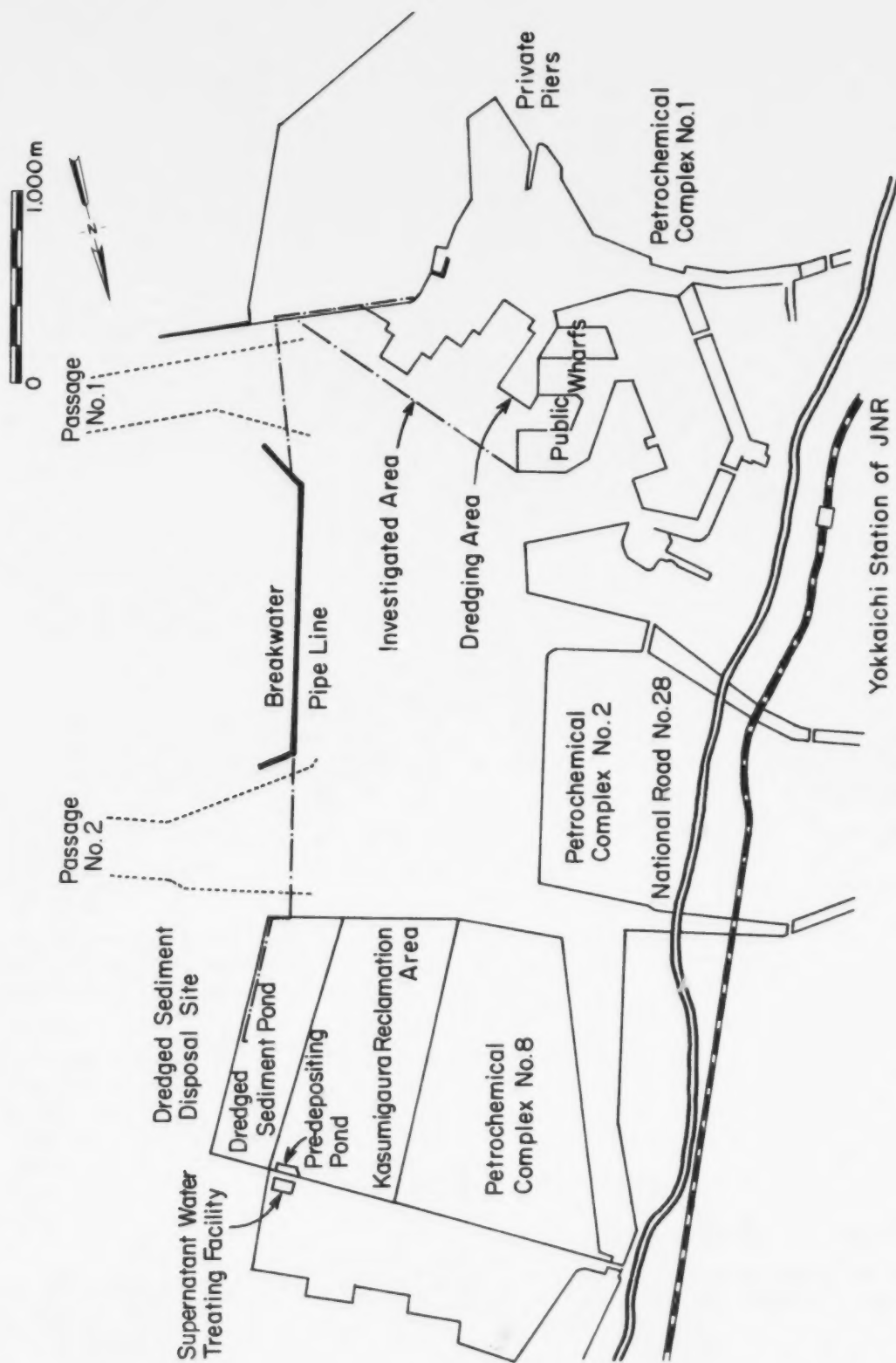


Figure 2. Work plan.

ACTUAL SITUATION

The final plan was decided on the basis of preliminary work done in March, 1975, in response to the supplementary opinion of the Council (Figure 2). The following explains the dredging method and the actual work situation.

DREDGING

Method

Dredges in use. We employed a dredge with a centrifugal pump, located under water, and a vacuum type dredge was used for the preliminary work. It was felt that these two dredge types would not cause secondary pollution.

The principal specifications for each dredge are as follows:

(1) Dredge with centrifugal pump

Dimensions of hull

Length:	36.0 m
Width:	11.0 m
Depth:	3.2 m
Draught:	1.8 m
Dredging depth:	2 - 23 m below the water level

Capacity

Sediment dredging volume:	300 - 700 m ³ /hr
Maximum pumping distance:	1,500 m
Slurry Solids content:	50% (average)
Main generator:	300 KVA × 2 units
Dredging pump:	110 KW

(2) Vacuum type dredge

Dimensions of hull

Length:	37.0 m
Width:	12.0 m
Depth:	3.0 m
Draught:	2.2 m
Dredging depth:	17 m

Capacity (at 7 kg/cm² of pumping pressure)

Sediment dredging volume:	210 - 510 m ³ /hr
Maximum pumping distance:	1,500 m
Slurry solids content:	60 - 80%

Main generator:	450 KVA × 3 units
Vacuum pump:	110 KW

Transportation Facility

(1) Pipe line

The distance from the dredging area to the disposal site was approximately 5 km and crossed the ship channel. Therefore, we decided to use a pipe line for transporting the dredged sediment to maintain use of the port facilities. This method prevented noxious odors from escaping along the transportation route.

To ensure safety, the pipe line was constructed in conformity with the Petroleum Pipe Line Enterprise Law. The pipe line consisted of 24 inch diameter steel pipes 12 m in length. Pipes on land were 2/5 inch thick and were connected with flanges. Those on the sea bottom were 1/2 inch thick and welded together. The regular working pressure in the pipe is 8 kg/cm² or less with an emergency pressure of 12 kg/cm². The velocity of flow in the pipe is more than 1.2 m/sec.

(2) Safety

To ensure the safety of the pipe line during the dredging work, a central monitoring system was installed on the station barge which would prevent an accident by stopping the main pump in case of trouble. The safety facilities are divided into a safety system and a monitoring system. Their installation is shown in Figure 3.

(i) Safety system

a. Pressure safety device

This is located on the station barge and, in case the discharge pressure of the main pump exceeds the regular working pressure of the pipe line, it will automatically stop the main pump.

b. Emergency shut-off valve

In case of trouble such as a leak, the pipe line can be shut off to minimize accidents and prevent siphoning of material back out of the pipe and into the environment.

c. Air removal device

This device keeps the submerged pipe which crosses the ship passage from floating and prevents any other trouble due to air mixed with the dredged slurrys.

(ii) Monitoring system

Each pressure gauge and flow meter is connected by wires to the central monitoring system on the station barge where monitoring is performed at all times. When the alarm functions, in case of trouble, immediately the super-

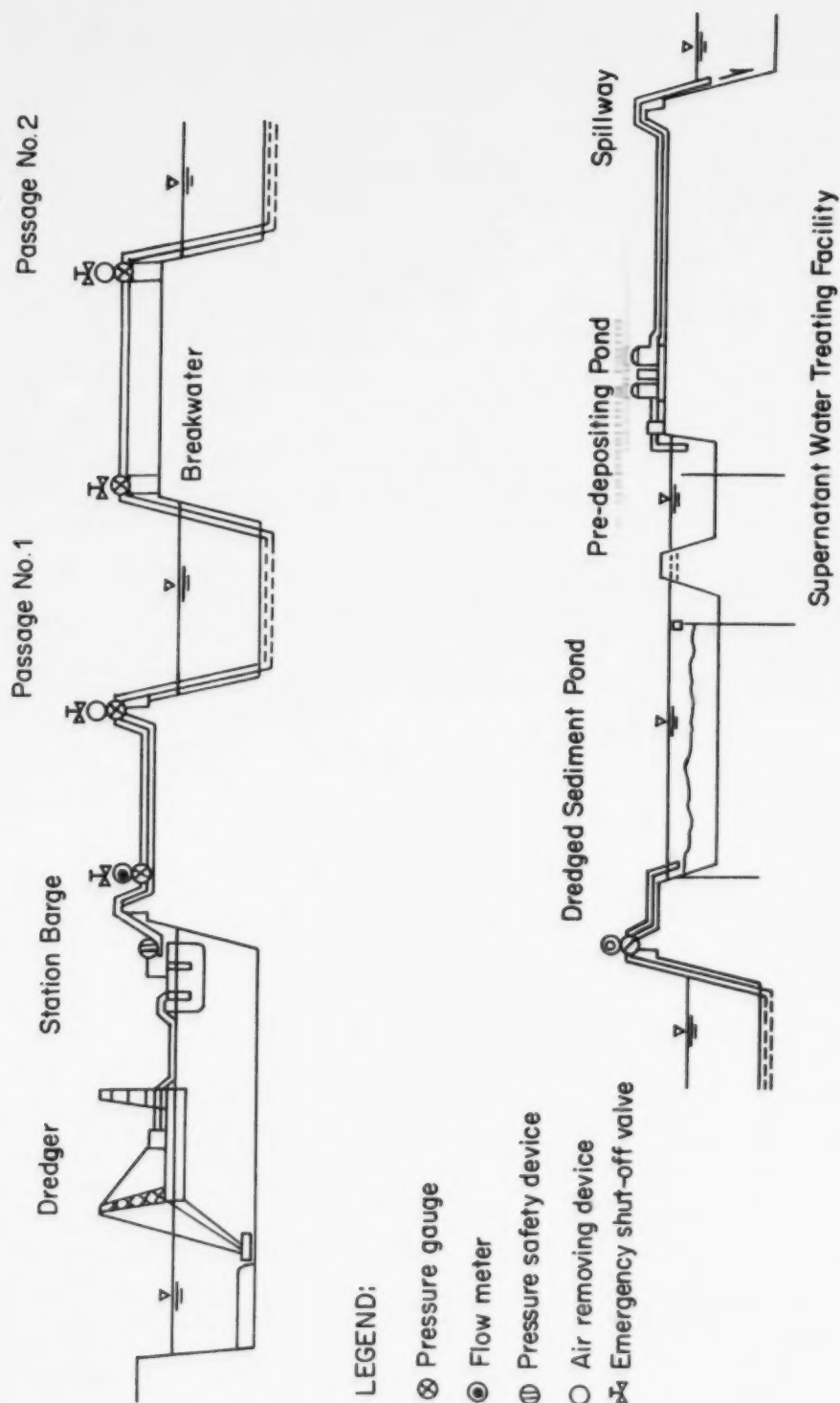


Figure 3. Safety system.

visor can manually stop the main pump on the station barge and instruct the patrol boat to check for trouble.

a. Pressure gauge

Leakages and other troubles are detected by the absolute and relative pressure differences at each of six points along the pipe line.

b. Flow meter

Flow meters are provided at each end of the pipe line to find leaks by checking the differential volume and to keep track of the amount of sediment transported.

(iii) On-site patrols

It is impossible for instruments to detect problems such as very small leaks and deformation of the pipes. Therefore, a patrol is performed at all times and visual inspection is made for early detection of problems.

Station barge. The pipe line is very long and a booster pump is required to transport the sediment. To shorten the project duration, two dredges were arranged in parallel, and a sump rehandler type station barge was employed.

The nominal principal items of the station barge are as follows:

Dimensions of hull	
Length:	90.3 m
Width:	19.8 m
Depth:	10.6 m
Capacity of hopper:	8,250 m ³
Capacity	
Pumping volume:	2,500 m ³ /hr
Total pump head:	66 m
Pumping distance:	6,000 m
Main generator:	2,000 KW

Operations

The dredging site includes the ship passage and anchorage which is surrounded by public wharfs and private piers. A large number of ships come and go across this area. Since the petrochemical complex is on the outskirts of the port, the private piers are crowded with many ships loaded with dangerous cargoes such as naphtha and LPG. It means this area is risky.

We are dredging with the utmost care for the safety of ships navigating in and out of the port. We often consult about control of navigation with the persons concerned with shipping companies and with those who have private piers and keep them informed of the dredging situation. The working period is normally limited to the hours from sunrise to sunset because we are required

to visually inspect for secondary pollution during the dredging work by looking for dispersion of sediments, floating oil, or leaking of dredge spoils.

Dredging is carried out by two different types of dredges. The vacuum type dredge is used in the area where the water depth is comparatively deep and the sediment is thick; the centrifugal pump dredge is used elsewhere.

The plan was to dredge 350 m³/hr in the regular sediments (pumping volume: 1,500 m³/hr at an average sediment content of 23%), 10 dredging hours per day and 25 working days per month. But in actual practice, the working efficiency was reduced to approximately 70% because of ships crossing, transfer of dredges and removal of obstacles from the dredge such as vinyl trash, tires, steel wires, and so forth.

The amount of dredged sediment per day became:

$$350 \text{ m}^3/\text{hr} \times 10 \text{ hr/day} \times 2 \text{ ships} \times 0.7 = 4,900 \text{ m}^3/\text{day}$$

The average amount of dredged sediment per month is approximately 120,000 m³.

DISPOSING OF SUPERNATANT WATER

Method

Dredged sediment pond

The dredged sediment pond is approximately 400,000 m² and its capacity is approximately 2,800,000 m³ (Figure 4). A retaining wall separates the pond from the sea. Steel sheet pilings are driven into the impermeable clay layer of the ocean floor and 3 mm thick vinyl sheets cover the upper face of the slope, as shown in cross section in Figure 5.

Treatment facility for supernatant water

(1) Settling pond

The supernatant water from the dredged sediment pond flows by gravity from the intake pit to the settling pond (Figure 6). Here, the suspended solids are retained and settle for 24 hours to alleviate the load on the supernatant water treatment facility and to maintain a constant treatment capacity.

The area of the settling pond is approximately 14,000 m² and its capacity is approximately 52,000 m³. The slope face of the embankment and the bottom surface are covered with vinyl sheets to prevent water seepage.

(2) Measuring tank

This is used for measuring volume flow of untreated water pumped from the settling pond to the mixing tank.

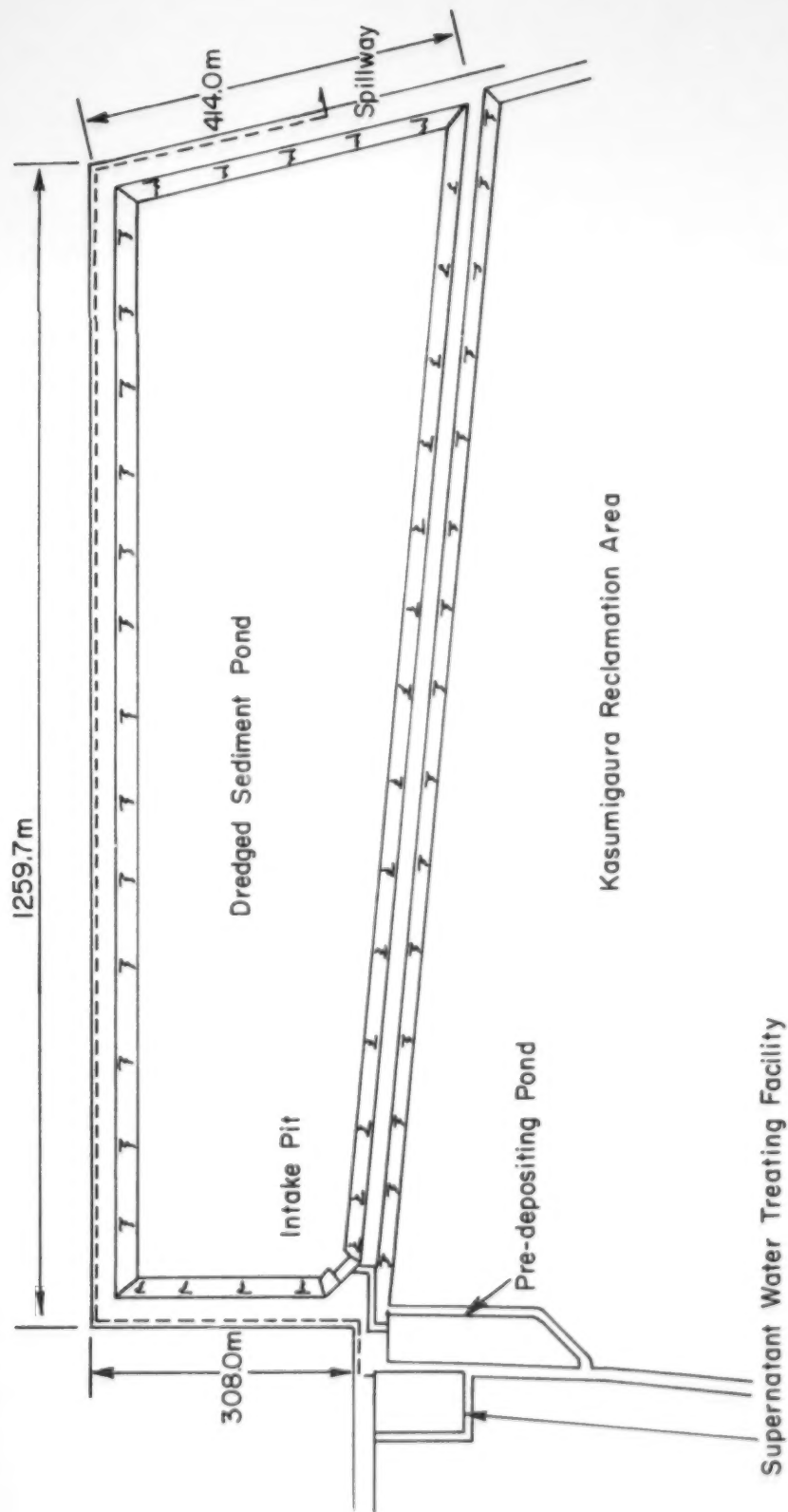


Figure 4. Dredged sediment disposal site.

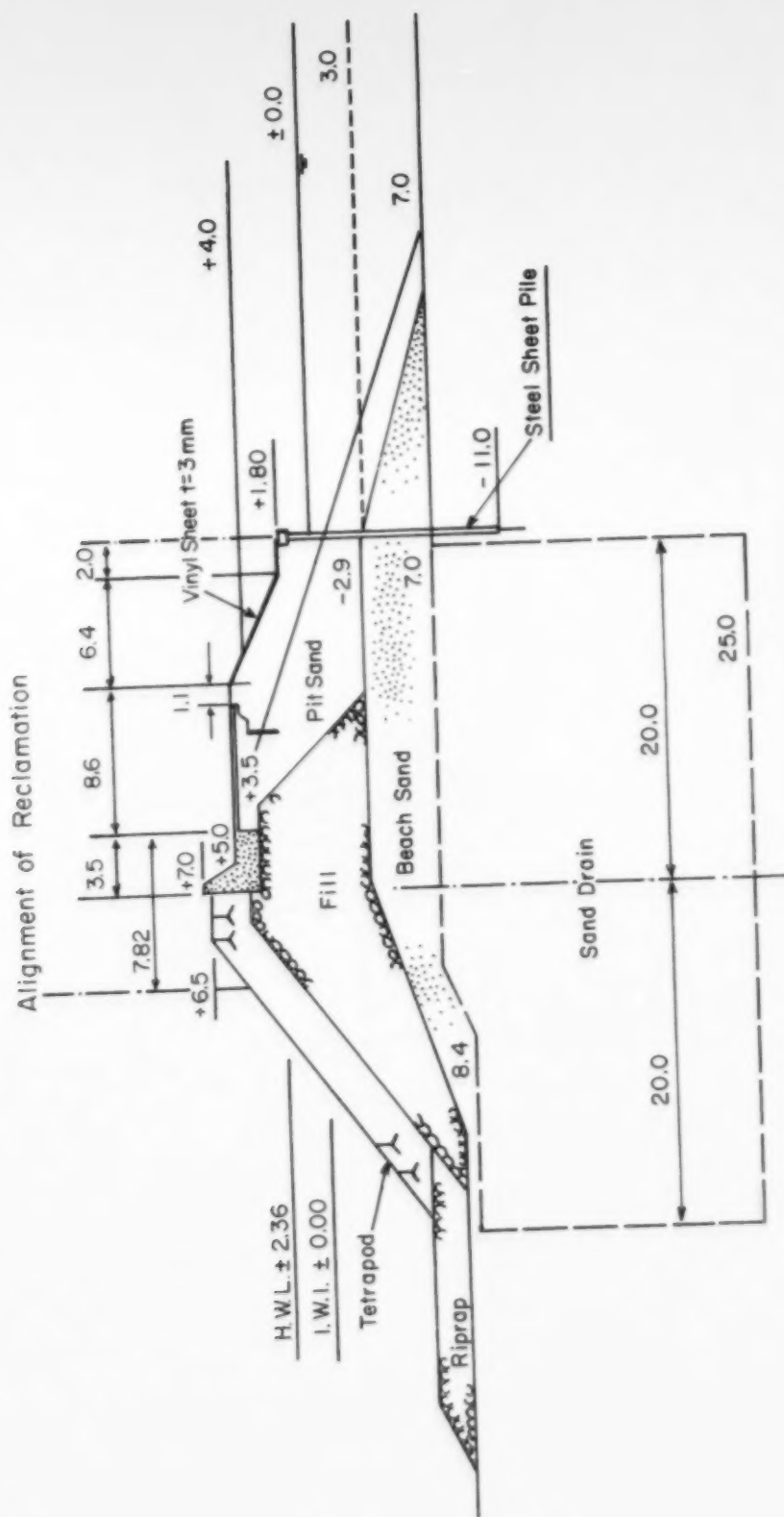


Figure 5. Revetment cross section of dredged sediment pond.

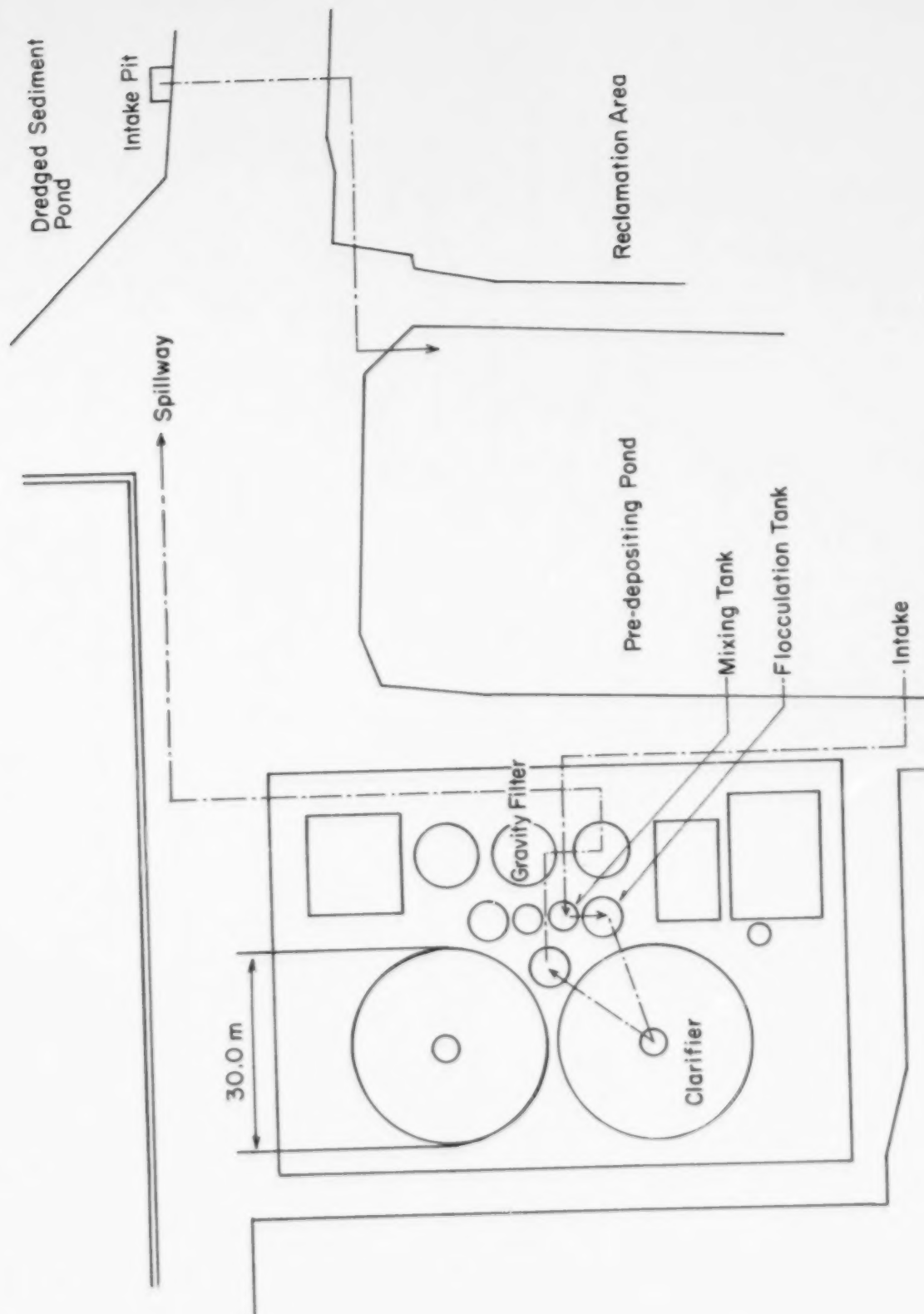


Figure 6. Supernatant water treating facility.

(3) Mixing tank

In this tank raw water is mixed with coagulants and pH buffers. The pH buffer is automatically introduced in the proper amount.

(4) Flocculation tank

The chemically treated water from the mixing tank is slowly mixed in this tank until flocculation occurs.

(5) Clarifier (two tanks: 30.0 m dia $\times$ 3.0 height)

The flocculant formed in the flocculation tank is allowed to settle and separate in the clarifying tanks. Settled material is collected by attached scrapers and is pumped out and circulated to the dredged sediment pond.

(6) Gravity filters (2 units: 9.45 m dia $\times$ 6.08 m height)

The supernatant water is routed to the filter where the remaining flocculant in the water is removed by a filter consisting of anthracite and sand.

After inspection, the treated water is piped out to sea.

Operations

The system for treating and disposing of supernatant water began on February 3, 1977, with a capacity of 22,000 m³/day. The results as of July 31, 1977, showed that the SS in raw water was less than 19 ppm. The disposal operation is now being performed without any problems.

MONITORING

Monitoring plan

Following is the outline of the monitoring plan established in accordance with the report of the Cost Allocation Council, the Interim Guidelines for Substratum Disposal (the Notification from the Director of the Water Quality Preservation Bureau of the Environmental Agency, May 30, 1974) and the guidance of the Investigation and Judgment Committee.

Basic monitoring points

We determined a general area where the impact of dredging should be prevented. Marine phenomena such as currents and tides and utilization of fishing grounds were taken into account. Four monitoring points were set on the boundary line of this area (Figure 7).

The parameters monitored at the basic monitoring points are:

- (1) Total mercury as representative of toxic substances.
- (2) Biological Indices: pH, DO, COD, and n-Hexane extraction.

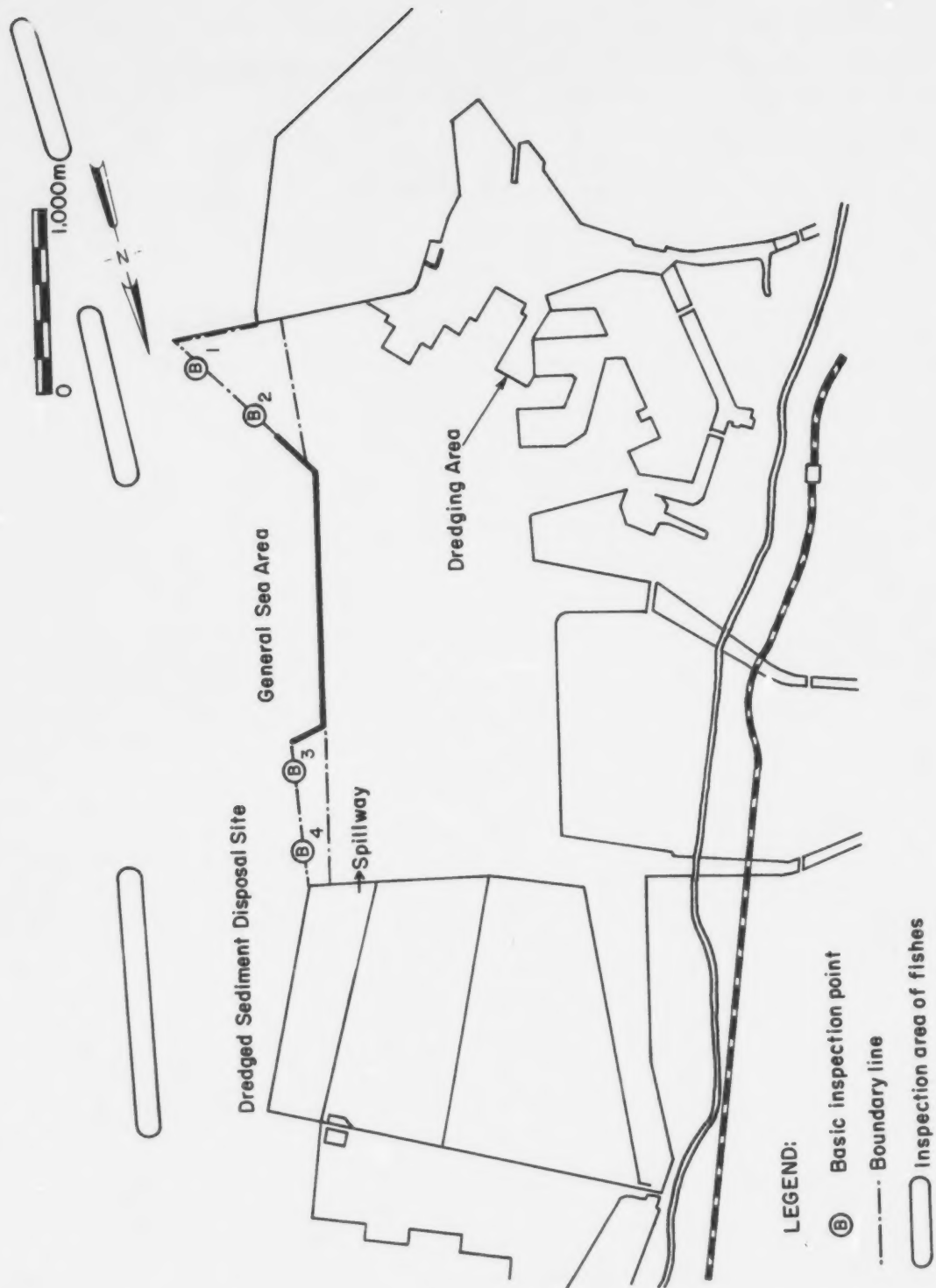


Figure 7. Inspection points.

(3) Light transmission.

The frequency of inspection is usually once a day at ebb tide. The frequency can be reduced to once a week, except for light transmission, in those cases where light transmission is correlated with the values of the other items. Then, monitoring is properly accomplished even though the frequency of inspection is reduced.

The sampling depths are approximately 0.5 m (surface layer), 2 m (intermediate layer), and 3 m above the bottom (bottom layer). DO is taken at 0.5 m and 2 m.

Standards are set according to the Environmental Quality Standards Regarding Water Pollution according to the Basic Law for Environmental Pollution Control. They are:

a.	Total Mercury:	less than 0.0005 ppm
b.	pH:	from 7.8 to 8.5
c.	DO:	more than 5 ppm
d.	COD:	less than 3 ppm
e.	n-Hexane extract:	less than 1 ppm

The criteria at each basic monitoring point are as follows:

(1) Total Mercury

The number of samples exceeding the standard shall be less than 36.8% of the total number of samples tested in a week.

(2) pH, DO, COD

The average value in a week shall be less than the standard.

(3) n-Hexane extract

The measured value shall not exceed the standard.

In case inspection shows that a criterion is violated the Investigation and Judgment Committee will be notified, their opinion heard, and the following measures will be taken.

(1) Total Mercury

Work shall be stopped immediately and necessary measures taken after investigating the causes.

(2) pH, DO, COD, n-Hexane extract

Inspection shall be increased along with investigation of the cause. Necessary corrective measures would include slowing down or suspending the dredging work. These measures shall be taken immediately to bring the project

into compliance with the standard. However, if the cause is not the dredging work, this response need not be applied.

Auxiliary monitoring points

In order to forecast changes of water quality at the basic monitoring points and to be able to make quick decisions whether or not dredging should be continued in case of pollution, auxiliary monitoring points are located between the basic inspection points and the dredging sites.

Inspection is carried out by measuring light transmission—normally four times a day. The standard for light transmission is $6 \times \alpha_i$, where α_i is the baseline value of α taken before dredging is begun, and is temporarily set at

$$\alpha = \frac{1}{L} \ln \frac{100}{T}$$

where L = Length of light passage (m)
 T = Absolute transmission (%)

Measurements are made at 3 m off the bottom. In case the standard is not met, the same measures as given in (2) above shall be taken.

Water quality adjacent to the work site

Abnormal turbidity and oil films in the vicinity of the work sites are looked for at all times. In case abnormal conditions are found, the same countermeasures as in (2) above shall be taken.

Spillway

The water from the spillway of the sediment disposal site is monitored for the following substances:

- (1) Toxic substances as specified by the Law Concerning Prevention of Marine Pollution and Maritime Disasters.
- (2) pH, SS, n-Hexane extration.
- (3) Turbidity, oil content (by carbon tetrachloride extraction and infrared spectrophotometry).

The frequency of monitoring is once a day for total mercury except when the mercury content is estimated as a function of turbidity and then the frequency can be reduced to once a week. Other toxic substances are observed once a month. SS and n-Hexane extractions are measured once a week. pH, turbidity, and oil content are continuously measured with an automatic measuring system.

The standards for toxic substances in the spillway were based on the Standard for Seawater Quality. They are:

a.	Total Mercury:	less than	0.005	ppm
b.	Arsenic:	less than	0.5	ppm
c.	Cadmium:	less than	0.1	ppm
d.	Lead:	less than	1	ppm
e.	Chromium (VI):	less than	0.5	ppm
f.	Organic Phosphorus:	less than	1	ppm
g.	Cyanide:	less than	1	ppm
h.	Alkyl Mercury:	not detectable		
i.	PCB:	less than	0.01	ppm

The following were set by the report of the Cost Allocation Council.

a.	pH:	from 7.8 to 9.0	
b.	SS:	less than 10	ppm
c.	n-Hexane extraction:	less than 2	ppm

When the results of the inspection procedures do not meet the standards, the effluent from the spillway shall be stopped immediately and necessary steps taken until the measured values satisfy the standards.

Noxious odors

Inspections are made so that the residential area shall not be inconvenienced by any offensive odor emitted from the dredge work. Methyl mercaptan, methyl sulfide and hydrogen sulfide are all specified by the Offensive Odor Control Law and are watched for by the project. The standard for these substances is set at a low enough level that most people cannot detect the odors in their daily lives. In case an abnormality is detected, necessary measures shall be taken together with investigation of the cause.

Fish

Mercury content in fish is investigated three times a year in the ocean area shown in Figure 7. The standard for total mercury is 0.4 ppm average for each species of fish. If the concentrations in any kind of fish exceeds the standard, the alkyl mercury content shall be inspected. The standard value for this is 0.3 ppm. In case the measured value exceeds the standard value, necessary steps shall be taken together with investigation of the cause.

Monitoring Operations

The results of inspection conducted under the inspection plan from December 13, 1976 (the start of dredging) to July 31, 1977, are as follows:

Basic monitoring points

(1) Total Mercury

The results of measurements for total mercury taken once a day until March 31, 1977, were all below the detectability limit of 0.0005 ppm. Therefore, the inspection frequency was reduced to once a week and the results were all non-detectable. The inspection was carried out by chemical analysis using

the method described in JIS K 0102. This document also describes COD and n-Hexane extraction methods.

(2) Items relating to the biotic environment

pH and DO were measured once a day and their weekly averages are shown in the attached table. This shows a tendency for pH to gradually increase from early summer to mid-summer. DO becomes unstable during the same period. We thought that these phenomena were related to the occurrence of red tide which was visually observed. Our baseline of water quality showed that the red tide often occurred during the same period. The measurements were carried out with a water quality analyzer.

The average daily values of COD in a week until March 31, and the weekly values in the succeeding period, are shown in the attached table. Values in excess of the standard were often observed from early summer to mid-summer. As mentioned above, we thought this phenomenon was caused by the occurrences of red tide.

n-Hexane extract was observed once a week and the results were all non-detectable at a limit of 0.5 ppm.

Auxiliary monitoring points

The maximum increase of α -values from the baseline, at 3 m above the bottom at each auxiliary monitoring point, was 3.57. This met the standard. For reference, the minimum α -value measured in the total period from beginning the work (once a day until March 31 and once a week in the succeeding period) was 0.82. The inspection was carried out with a "transmissometer."

Spillway

(1) Toxic substances

(i) Total mercury

The results of daily inspections until March 31 were all non-detectable. The frequency of inspection was therefore reduced to once a week, and results were still all non-detectable.

(ii) Other toxic substances

The once-a-month results were all non-detectable. The analysis was carried out according to JIS K 0102, using either gas chromatography or the thin-layer chromatography (Molybdenum blue) method.

Limits of detectability are as follows:

a.	Arsenic:	0.002	ppm
b.	Cadmium	0.001	ppm
c.	Lead:	0.01	ppm
d.	Chromium (VI):	0.05	ppm
e.	Organic phosphorus		
	(parathion, methyl parathion, EPN):	0.1	ppm
	(methyl demeton):	0.15	ppm
f.	Cyanide:	0.01	ppm
g.	Alkyl mercury:	0.0005	ppm
h.	PCB:	0.0005	ppm

(2) pH, SS, n-Hexane extract

a. pH

The supernatant water treatment facility is provided with an automatic pH adjusting system. An industrial pH monitor is used for continuous inspection.

b. SS

The results of weekly inspection gave 7.9 ppm as the maximum value, which met the standard. The analysis was carried out according to JIS K 0102.

c. n-Hexane extract

The results of weekly inspection were all non-detectable.

(3) Turbidity and oil content

a. Turbidity

The supernatant water treatment facility is designed so the automatic circulator works in cases of high turbidity. The measurements are carried out by a turbidity monitor.

b. Oil content

When the oil content is abnormal, an alarm is given. Measurements are made by an oil content monitor.

2-4 Others

The results of the watch for noxious odors and the inspection of fish revealed no problems.

FUTURE PROBLEMS

REMOVAL OF UNCONSOLIDATED BOTTOM SEDIMENTS

Sediments with high water content cause problems in the dredging area. This 30 - 50 cm layer on the bottom is liquid enough to flow aside while dredging and is therefore difficult to remove completely. Our remaining

problem is to dredge the sediment completely by improving the dredge equipment and the dredging methods.

SURFACE TREATMENT

The supernatant water from the dredged sediment pond is piped into the sea after filtration. The problem to solve in the future is how to dehydrate the remaining sediment which has a high water content, and to cover it with soil to finish the disposal. In recent years, surface treatment has been done at many places, but few of these examples disposed of sediment with a high oil content. Therefore, careful investigation is necessary along with the final disposal of the spoils.

CONCLUSION

It is important to carefully investigate the area to be dredged. When this project began we found that vinyl, tires, steel wires, and other trash would clog the dredge pipe and this unexpectedly lowered the dredging capacity and prolonged the work.

Sometimes the measured values of the biological indices at the monitoring points exceed the standards, but not due to reasons caused by dredging. If this is the case it is not necessary to slow down or halt the work. The problem is to determine quickly and easily the cause of the high values.

Usual causes are the red tide and organically-rich river water flowing into the areas. These may be effectively judged by visual means except where turbidity is high. Then only the surface is visible and a transmissometer may be used to establish the turbidity, particularly around the dredging site, after which the dredging effect may be accounted for and the excess attributed to the other causes.

Color measurements of suspended solids and ignition loss values are two other possible methods of discriminating among sources of contamination.

At this time, approximately 30% of the sediment has been dredged. Though we can't yet evaluate the whole project, as of now there have been no problems with the described methodology.

The standard values at the auxiliary monitoring points were determined from baseline investigations of the daily fluctuation of the α -value. This was based on the concept that any artificial act should not be permitted to contaminate the natural world. We have maintained this concept since we began plans for the project, and we will continue to do so until the completion of the work.

Table. RESULTS OF INSPECTION (December 13, 1976 - July 31, 1977)

Table. RESULTS OF INSPECTION (December 13, 1976 - July 31, 1977)																											
Item	Point	Period		Dec.13	Dec.20	Dec.27	Jan. 2	Jan.10	Jan.17	Jan.24	Jan.31	Feb. 7	Feb.14	Feb.21	Feb.28	Mar. 7	Mar.14	Mar.21	Mar.28								
		- 19	- 26	-Jan.2	- 9	- 16	- 23	- 30	-Feb.6	- 18	- 20	- 27	-Mar.6	- 13	- 20	- 27	- 27	-Apr.8									
P H	Basic	1	8.16	8.21	8.30	8.23	8.13	8.22	8.22	8.22	8.23	8.23	8.20	8.20	8.37	8.35	8.22	8.23	8.24								
	Basic	2	8.19	8.21	8.37	8.21	8.18	8.24	8.24	8.30	8.25	8.26	8.27	8.23	8.36	8.41	8.25	8.25	8.30								
	Basic	3	8.16	8.26	8.37	8.26	8.20	8.20	8.20	8.30	8.23	8.26	8.26	8.24	8.31	8.41	8.25	8.28	8.32								
	Basic	4	8.10	8.23	8.27	8.23	8.18	8.24	8.24	8.31	8.24	8.25	8.28	8.24	8.28	8.38	8.24	8.28	8.31								
D O (ppm)	Basic	1	8.10	8.58	7.80	9.20	9.28	8.98	8.98	10.15	9.29	9.26	9.25	9.33	10.26	10.69	8.23	7.67	7.46								
	Basic	2	8.15	8.59	7.90	9.21	9.21	9.03	9.03	10.06	9.17	9.32	8.81	9.29	9.92	10.44	7.91	7.43	7.40								
	Basic	3	7.51	8.33	7.90	9.20	8.94	8.74	9.58	9.16	8.76	8.76	8.61	9.03	9.52	10.15	7.54	7.53	7.31								
	Basic	4	7.54	8.03	8.00	9.03	8.95	8.58	9.42	8.96	8.97	8.97	8.68	8.73	9.49	9.64	7.24	7.72	7.23								
C O D (ppm)	Basic	1	1.4	1.4	1.5	1.4	1.7	1.6	1.6	1.0	1.5	1.5	1.3	1.1	1.7	2.9	1.4	1.7	1.1								
	Basic	2	1.6	1.5	1.1	1.4	1.7	1.4	1.4	0.9	1.3	1.3	1.0	1.1	1.7	1.9	1.5	1.4	1.1								
	Basic	3	1.3	1.4	1.7	1.3	1.7	1.1	1.1	1.0	1.3	1.2	1.2	1.2	1.7	2.2	1.6	1.5	1.1								
	Basic	4	1.3	1.5	1.9	1.3	1.4	1.2	1.2	1.1	1.2	1.1	1.0	1.1	1.7	1.8	1.6	1.9	1.0								

Item	Point	Period		Apr. 4		Apr. 11		Apr. 18		Apr. 25		May 2		May 9		May 16		May 23		May 30		Jun. 6		Jun. 13		Jun. 20		Jun. 27		Jul. 4		Jul. 11		Jul. 18		Jul. 25	
		Period		Apr. 4		Apr. 11		Apr. 18		Apr. 25		May 2		May 9		May 16		May 23		May 30		Jun. 6		Jun. 13		Jun. 20		Jun. 27		Jul. 4		Jul. 11		Jul. 18		Jul. 25	
P H	1			8.32	8.29	8.13	8.25	8.13	8.25	8.25	8.14	8.14	8.46	8.46	8.16	8.35	8.35	8.27	8.27	8.31	8.31	8.07	8.16	8.16	8.22	8.22	8.24	8.23	8.24	8.24	8.29	8.29	8.46	8.46	8.50	8.50	
	2			8.88	8.88	8.25	8.88	8.25	8.88	8.88	8.18	8.18	8.46	8.46	8.18	8.88	8.88	8.89	8.89	8.88	8.88	8.14	8.21	8.21	8.28	8.28	8.28	8.42	8.28	8.28	8.86	8.86	8.86	8.86	8.44	8.44	
	3			8.44	8.29	8.29	8.30	8.29	8.30	8.30	8.17	8.17	8.52	8.52	8.14	8.84	8.84	8.44	8.44	8.45	8.45	8.18	8.16	8.16	8.25	8.25	8.25	8.42	8.25	8.25	8.81	8.81	8.86	8.86	8.50	8.50	
	4			8.39	8.81	8.28	8.32	8.28	8.32	8.32	8.16	8.16	8.54	8.54	8.12	8.86	8.86	8.42	8.42	8.47	8.47	8.12	8.15	8.15	8.28	8.28	8.28	8.55	8.28	8.31	8.44	8.44	8.50	8.50	8.50	8.50	
D O (ppm)	1			7.88	6.91	7.41	7.25	7.41	7.25	7.25	7.54	7.54	8.50	8.50	5.99	6.49	6.49	6.21	6.21	5.76	5.76	4.48	7.54	7.54	9.19	9.19	8.12	8.12	8.08	9.36	11.11	11.11	11.36	11.36	11.14	11.14	
	2			7.29	6.51	7.36	7.42	7.36	7.42	7.42	7.46	7.46	8.57	8.57	5.43	6.37	6.37	6.50	6.50	5.93	5.93	4.24	7.64	7.64	9.73	9.73	8.88	8.88	8.09	9.60	11.36	11.36	11.46	11.46	11.14	11.14	
	3			7.31	6.45	7.01	7.28	7.01	7.28	7.28	7.19	7.19	8.59	8.59	5.69	6.21	6.21	7.08	7.08	6.46	6.46	5.04	7.84	7.84	8.55	8.55	9.14	9.14	8.19	9.46	11.14	11.14	11.46	11.46	11.14	11.14	
	4			7.15	6.42	7.09	7.23	7.09	7.23	7.23	6.88	6.88	8.47	8.47	5.09	6.17	6.17	6.71	6.71	6.66	6.66	8.88	7.29	9.13	9.13	10.85	10.85	8.90	11.04	11.04	11.64	11.64	11.64	11.64	11.64	11.64	
C O D (ppm)	1			1.8	1.7	1.4	1.9	1.4	1.9	1.9	1.7	1.7	1.7	1.7	1.2	2.1	2.1	3.3	3.3	3.1	3.1	2.6	2.7	2.7	4.0	4.0	3.3	3.3	4.4	2.2	3.7	3.7	2.5	2.5	2.5	2.5	
	2			1.0	1.7	1.5	1.7	1.5	1.7	1.7	1.8	1.8	2.5	2.5	1.3	1.9	1.9	3.4	3.4	2.3	2.3	2.7	2.7	2.7	4.0	4.0	3.3	3.3	4.4	2.0	3.7	3.7	2.5	2.5	2.5	2.5	
	3			1.6	1.7	0.9	1.7	0.9	1.7	1.7	1.9	1.9	2.1	2.1	1.2	2.0	2.0	3.6	3.6	3.1	3.1	2.1	2.5	2.5	4.0	4.0	3.8	3.8	4.1	2.4	3.7	3.7	2.5	2.5	2.5	2.5	
	4			1.4	1.7	1.8	1.9	1.8	1.9	1.9	1.5	1.5	2.8	2.8	1.1	2.3	2.3	3.3	3.3	3.3	3.3	2.3	2.2	2.2	3.6	3.6	4.1	4.1	4.1	2.8	3.7	3.7	2.5	2.5	2.5	2.5	

ACCUMULATION OF METHYL MERCURY IN RED SEA BREAM
(*Chrysophrys major*) VIA THE FOOD CHAIN

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SUMMARY

Accumulation of methyl mercury in red sea bream (*Chrysophrys major*) results from food chain accumulations—from diatoms to copepoda to the juvenile bream.

Diatoms were reared for 24 hours in filtered sea water containing 5.0 ppb methyl mercury. Methyl mercury taken up by the diatoms reached a concentration of 3.45 ppm. The diatoms containing methyl mercury were then fed to the copepoda for 4 days. The concentration of methyl mercury in the copepoda reached 3.14 ppm. The copepoda were then fed to the juvenile red sea bream for 10 days. Methyl mercury concentration in the fish reached 3.10 ppm.

The concentration of methyl mercury in the diatoms and the copepoda was about 2,000 times as much as that of the culture solution. The increase of methyl mercury from food to fish was about one. However, the amount of methyl mercury taken up by the juvenile bream was about 120 times as much as that of the control.

INTRODUCTION

The mechanism of accumulation of methyl mercury in fish is not yet known. There are several hypotheses such as: methyl mercury is taken up from sea water directly through the gills, from the digestive organs via food containing methyl mercury, or from the gills and/or digestive organs via bottom sediments which contain methyl mercury.

The author and his coworkers have studied the mechanism of methyl mercury accumulation in the fish and have learned that accumulation was either directly through the gills from sea water containing methyl mercury and/or via food containing methyl mercury. Tarao, Tabata and Yasuhara have studied the first hypothesis and found no significant direct uptake from suspended solids.

The accumulation in fish via the food chain was not understood because of the variety of food consumed daily as well as changes in ration over the life of the fish. To clarify the understanding of the process of methyl mercury

accumulation the author and his coworkers carried out the following experiments on the food chain of diatom (Skeletonema costatum) to copepoda (Acartia clausi) and copepoda to red sea bream (Chrysophrys major).

EXPERIMENTAL METHOD

The diatom used in this experiment was obtained from the Aitsu Marine Biological Station of Kumamoto University. It was isolated from other species and cultured in a solution of 400 grams potassium nitrate, 40 grams dibasic sodium phosphate, 20 grams sodium silicate, 10 grams ferric chloride, 20 grams Krewat and 1 ton of filtered sea water. The copepoda used in this experiment was obtained from a breeding pond in the Ohoyano Branch of the Biological Station of Kumamoto Prefecture. The red sea bream used in this experiment was obtained from a fish rearing tank at the Ohoyano Branch Station.

MERCURY ACCUMULATION IN THE DIATOM (Table 1)

1) Experiment A

A culture solution containing 0.5 ppm mercuric chloride and the diatom were put in a 500 liter fish rearing tank and the culture solution was aerated by an air-pump for 24 hours. Then the diatoms were collected with a plankton net and frozen. Methyl mercury in the diatoms was measured by gas-chromatography and total mercury by flameless atomic absorption spectrophotometry.

2) Experiment B

A culture solution containing 0.5 ppb methyl mercury and diatoms were put in a 500 liter fish rearing tank and the culture solution was aerated by an air-pump for 24 hours. Then the diatoms were collected and frozen. Methyl mercury and total mercury in the diatoms were measured.

3) Experiments C and D

A culture solution containing 5.0 ppb methyl mercury and diatoms were added to a 1000 liter fish rearing tank and a 500 liter fish rearing tank and the culture solutions aerated by an air-pump for 24 hours. The diatoms obtained from the tanks C and D were put together and frozen. Methyl mercury and total mercury in the diatom were measured.

MERCURY ACCUMULATION IN COPEPODA (Table 2)

1) Experiment E

Filtered sea water containing 0.5 ppb mercuric chloride and copepoda were added to a 500 liter fish rearing tank and the water aerated by an air-pump for 24 hours. Then the copepoda were collected and frozen. Methyl mercury and total mercury were measured.

TABLE 1. EXPERIMENTS ON MERCURY INTAKE IN DIATOMS.

Experiment →	A	B	C	D
Rearing tank	500 l	500 l	1000 l	500 l
Mercury concentration in Culture solution	MC 0.5 ppb	MMC 0.5 ppb	MMC 5.0 ppb	MMC 5.0 ppb
Experimental period	24 hr.	24 hr.	24 hr.	24 hr.
Initial cell number	$32 \times 10^6/1$	$26 \times 10^6/1$	$19 \times 10^6/1$	$79 \times 10^5/1$
Final cell number	$32 \times 10^6/1$	$33 \times 10^6/1$	$12 \times 10^6/1$	$94 \times 10^5/1$
Methyl mercury in diatoms	0.016 ppm	0.93 ppm	3.45 ppm	
Total mercury in diatoms	0.77 ppm	1.05 ppm	4.50 ppm	
Magnification of total Hg	1540	2100	900	900
Magnification of MMC	n.a.	1860	690	690

TABLE 2. EXPERIMENTS ON MERCURY INTAKE IN COPEPODA.

Experiment →	E	F	G	J
Rearing tank	500 l	500 l	500 l	500 l
Mercury concentration in Sea water	MC 0.5 ppb	MMC 0.5 ppb	0.0	MMC 5.0 ppb
Bait	none	none	Diatom from Exp. C	none
Experimental period	24 hr.	24 hr.	4 days	24 hr.
Population	400/1	1000/1	200/1	1000/1
Methyl mercury in copepoda	0.038 ppm	3.10 ppm	3.14 ppm	5.0 ppm
Total mercury in copepoda	0.28 ppm	3.50 ppm	4.30 ppm	5.6 ppm
Magnification of total Hg	560	7000	0.96	1120
Magnification of MMC	n.a.	6200	0.91	1000

MMC = methyl mercury chloride
MC = mercuric chloride

TABLE 3. EXPERIMENT H. MERCURY INTAKE IN JUVENILE RED SEA BREAM.

	initial day	after 1 day	after 2 days	after 3 days	after 4 days	after 5 days	after 6 days	after 7 days	after 8 days	after 9 days	after 10 days
Juvenile red sea bream	2113	3092	3063	2977	2735	1693	1648	1494	1386	1363	703
	650	21	29	86	242	352	45	154	108	23	13
	mean length (cm)	9.6	8.2	8.0	8.9	9.5	10.1	10.4	10.9	11.8	11.9
Ration	copepoda (g) (from experiment J)	8.7	3.7	3.5	11.5	22.0	32.5	34.0	35.5	27.4	
	brine shrimp (g)	--	22.5	30.0	25.0	10.0	--	--	--	--	--
Methyl mercury in ration (ug)		43.5	63.5	77.5	107.5	130.0	147.5	162.5	177.5	137.0	--
	Temperature (°C)	--	25.3	24.2	23.0	22.2	22.9	23.4	24.9	25.5	25.2

2) Experiment F

Filtered sea water containing 0.5 ppb methyl mercury and copepoda were added to a 500 liter fish rearing tank and the water was aerated by an air-pump for 24 hours. Then the copepoda were collected and frozen. Methyl mercury and total mercury were measured.

3) Experiment G

Filtered sea water without any mercury and copepoda was added to a 500 liter fish rearing tank and the sea water was aerated by an air-pump for 4 days. The diatom obtained from experiment C was fed to the copepoda as the ration for 4 days. The methyl mercury concentration in the diatom was 3.4 ppm (wet weight basis) and the total mercury concentration was 4.5 ppm. After 4 days, the copepoda were collected and frozen. Methyl mercury and total mercury in the copepoda were measured.

MERCURY ACCUMULATION IN RED SEA BREAM

1) Experiment H (Table 3)

Filtered sea water and juvenile red sea bream were added to a 500 liter fish rearing tank H and the sea water was aerated by an air-pump for 10 days. Filtered sea water was continuously supplied to the fish rearing tank and the water level was maintained by an over-flow system. The copepoda obtained from experiment J (identical to experiment F) were fed to the young red sea bream as their ration for 10 days. The methyl mercury concentration in the copepoda was 5.0 ppm and the total mercury concentration in the copepoda was 5.6 ppm. Both copepoda and brine shrimp (*Artemia salina*) were used as the ration for days 1-4 in this experiment because the amount of copepoda containing methyl mercury was not sufficient to last for 10 days. The brine shrimp were reared in filtered sea water containing 5.0 ppb methyl mercury (experiment K) and the methyl mercury and total mercury concentration in them was 2.01 ppm and 2.15 ppm, respectively. At 5 days and 10 days, the bream were collected and frozen. Then methyl mercury and total mercury were measured.

2) Experiment I (Control)

Filtered sea water and the juvenile of red sea bream were added to a 500 liter fish rearing tank. The sea water in the tank was aerated by an air-pump for 7 days. Filtered sea water was continuously supplied to the tank and the water level was maintained by an over-flow system. Copepoda and brine shrimp reared in sea water without addition of methyl mercury were fed to the young bream as their ration for 7 days, after which fish were collected with a net and frozen. Then methyl mercury and total mercury were measured.

RESULTS

Mercury accumulation in diatoms is given in Table 1. Table 3 gives the results of the red sea bream.

DISCUSSION

In experiment A with 0.5 ppb mercuric chloride, the total mercury concentration in the diatoms was 1540 times as much as the culture solution. In experiment B with 0.5 ppb of methyl mercury chloride the methyl mercury concentration in the diatoms was 1860 times as much as the culture solution. In experiment C with 5.0 ppb of methyl mercury chloride, the methyl mercury concentration in the diatoms was 690 times as much as that in the culture solution. Inorganic mercury was accumulated at a slower rate than methyl mercury and accumulation at the low mercury concentrations was at a higher relative rate than in the high level concentration.

In experiment E containing 0.5 ppb of mercuric chloride the total mercury concentration in the copepoda was 560 times as much as the sea water. In experiment F containing 0.5 ppb of methyl mercury chloride, the methyl mercury concentration in the copepoda was 6200 times as much as that in the sea water. In experiment J containing 5.0 ppb of methyl mercury chloride, the methyl mercury concentration in the copepoda was 1000 times as much as in the sea water. In experiment K containing 5.0 ppb of methyl mercury chloride the methyl mercury concentration in the brine shrimp was 400 times as much as that in the sea water. In experiment G with a ration of diatoms containing 3.4 ppm methyl mercury the methyl mercury concentration in the copepoda was 0.91 times as much as that in the diatoms. The level of intake of inorganic mercury was markedly low in the diatoms, and the relative rate of intake at low mercury concentrations was higher than at high concentrations. The methyl mercury intake of copepoda was higher than that of the brine shrimp. The total amount of methyl mercury taken up by the copepoda for 4 days was almost the same as that in the copepoda cultured for 24 hours in sea water containing 5.0 ppb methyl mercury.

In experiment H (Table 3) involving the diatoms to copepoda to fish food chain, the methyl mercury concentrations in the young bream after 5 days and 10 days were 0.6 and 0.75 times as much as that in the ration, respectively. The rate of concentrations is evidently low because the methyl mercury concentration in the infant red sea bream after 10 days was at about the same level as that of the diatom and the copepoda used as the food. However, the total quantity of methyl mercury in the bream after 10 days was about 120 times as much as that of the control. The quantity of methyl mercury fed to the fish at 5 days and 10 days were 3.53 μg and 7.79 μg per gram of body weight, respectively. The quantity of methyl mercury taken in by the bream after 5 days and 10 days was 2.34 μg and 3.10 μg per gram, respectively. Since the red sea bream used in these experiments were in the juvenile stage, growth was quick and the body weight after 10 days was about 2 times that of the first day. Therefore, the methyl mercury concentration in the young red sea bream after 10 days may have been unexpectedly low.

Growth of the diatoms was slightly inhibited by the 0.5 ppb of methyl mercury in sea water. The sensitivity of the plankton to mercury was higher than that of the fish. Therefore, plankton may be used as indicators of methyl mercury pollution.

TABLE 4. MERCURY ($\mu\text{g/g}$) ACCUMULATED IN DIATOMS, COPEPODA, BRINE SHRIMP AND JUVENILE RED SEA BREAM (ppm wet weight basis).

	juvenile red sea bream			copepoda fed to fish			brine shrimp fed to fish			
	initial day		after 5 days	after 10 days	control	reared in MMC 5.0 ppb 24 hr.	control	reared in MMC 5.0 ppb 24 hr.	control	
Methyl mercury	0.025	2.34	2.81	3.10	0.026	5.00	0.008	2.01	0.007	
Total mercury	0.029			3.60	0.29	5.60	0.063	2.15	0.062	

	copepoda			diatom			
	reared in MC 0.5 ppb 24 hr.	reared in MMC 0.5 ppb 24 hr.	fed diatom containing MMC	control	reared in MC 0.5 ppb 24 hr.	reared in MMC 0.5 ppb 24 hr.	reared in MMC 5.0 ppb 24 hr.
Methyl mercury	0.038	3.10	3.14	0.008	0.016	0.93	3.45
Total mercury	0.28	3.50	4.30	0.050	0.77	1.05	4.50
							0.004
							0.012

CONCLUSION

From these experiments, it was concluded that the most effective pathway for the accumulation of methyl mercury in the red sea bream is not via the food chain but from sea water directly through the gills.

THE RELATIONSHIP BETWEEN SEDIMENTS AND BENTHOS IN MIKAWA BAY

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SUMMARY

In this study an attempt has been made to clarify the relationship between the sediments and the benthos in Mikawa bay. The calculation of the Sediment Pollution Index (SPI) and its significance are presented. A correlation analysis is made between factors of sediment quality and SPI on one hand and factors such as predominant benthic species on the other.

The results obtained in this study have indicated that, to a certain extent, there are correlations between some items of the first group and some items of the second group, e.g., correlations have been observed between SPI and species number with a linear regression formula of $y = -0.775x + 25.301$ ($r = -0.765$), and between SPI and percent crustacea with $y = -0.903x + 22.292$ ($r = -0.715$).

INTRODUCTION

Pollution in sea water is generally so variable that it can be easily affected by temporary changes in meteorological and oceanographic conditions. But pollution in the sediments and in the benthos represents average pollutant conditions and cumulative tendencies. The benthos can thus serve as an index to indicate productivity and environmental conditions.

The kind of benthic community found is determined in part by physical and chemical factors of the sediment and overlying water and the local bathymetry. Larvae of 70 to 80% of benthic organisms float. These larvae require specific bottom types on which to settle. Benthos usually feed on suspended organic matter, organic detritus in the sediment and microalgae. Fish productivity can be estimated by using the standing crops of benthos in a bay because of the correlation between fish catch and the volume of benthos.

In order to continue this line of study, investigations into sediment-benthos relationships were carried out by the author and others at the Mei and Aichi prefectural fisheries experiment stations. Data on water quality, sediments, benthos, plankton, juvenile fish and bottom currents were obtained in Ise and Mikawa bay. This took three years—from May 1969 to March 1972—but analysis has not yet proceeded far enough to implement pollution control measures. Therefore this study only attempts to clarify the relationship between the sediments and the benthos in Mikawa bay.

DATA AND ANALYTIC METHODS

Sediment and benthos samples were collected five different times with a Smith-McIntyre grab sampler (0.1 m²) at 30 stations in Mikawa bay—May, July, September, and November in 1969 and March in 1970. The samples have been sorted into five regions in the bay—the eastern inner part (region A), the southern central part (region B), the mouth (region C), the northern inner part (region D) and the northern central part (region E)(Figure 1). A general description of each region has been derived on the basis of the averages of the sampling measures, and a few studies have been made regarding the relationship between sediment quality and benthos in the bay by using these averages.

RESULTS

AVERAGE SEDIMENT QUALITY

Sediment quality is summarized by region in Table 1 and Figure 2.

Fines content (below 0.074 μ)

The fines content indicated 13.6 to 89.0% (54.1% average) over all regions. Region C showed 13.6 to 32.5% (22.7% average) which was the lowest range of values. The highest range of values was in region E which showed 66.0 to 89.0% (81.5% average). All the regions can be ordered approximately as C < A < D < B < E. Seasonal changes were not observed in any of the regions.

Ignition Loss (Fraction ash free dry weight)

A range of 4.5 to 15.5% (10.3% average) existed over all the regions. Region C showed the lowest range—4.5 to 8.7% (6.5% average)—while the highest range of 13.2 to 15.5% (14.4% average) was observed in region E. All the regions can be ordered approximately as C < A < B < D < E. Seasonal changes were not observed in any of the regions.

COD

Some 1.9 to 29.6 mg/g (13.2 mg/g average) were observed over the whole bay. As with the fines content and ignition loss, region C showed the lowest range of values of 1.9 to 4.9 mg/g (3.9 mg/g average), while region E indicated the highest range of 14.5 to 29.6 mg/g (21.8 mg/g average).

The regions may be ordered approximately as C < B < D < A < E. Furthermore, although a trend of gradual reduction was observed over time in regions A and B, no tendency for a transitional change was observed in the other regions.

Sulfide

The range over the whole area was 0.05 to 0.87 mg/g (0.30 mg/g average). From 0.05 to 0.15 mg/g (0.10 mg/g average) was the lowest range of values and was observed in region C. Region A had the highest range of 0.24 to 0.87 mg/g

TABLE 1. AVERAGE SEDIMENT QUALITY IN EACH REGION OVER THE SAMPLING PERIOD.

Region	Item Time		Depth (m)	Fine mud content (%)	Ignition loss (%)	COD (mg/g)	Sulfide (mg/g)	Eh (mV)	Humic acid (p')
A	1969	5	6.5	73.6	13.3	22.6	0.75	-	-
		7	7.2	29.9	7.0	17.4	-	-206	0.430
		9	6.5	52.7	8.3	16.9	0.87	-372	0.595
		11	8.0	27.0	5.0	13.0	0.26	-179	0.600
	3	8.0	64.2	14.5	-	0.24	-194	0.627	
B	1969	5	15.1	74.1	12.3	15.9	0.30	-	-
		7	21.6	54.2	8.6	12.1	-	-174	0.276
		9	15.1	68.8	8.5	8.9	0.33	-303	0.232
		11	14.0	50.0	10.7	9.8	0.27	-164	0.251
	3	16.0	63.6	13.4	9.8	0.19	-323	0.377	
C	1969	5	23.1	22.7	6.6	4.4	0.15	-	-
		7	24.6	32.5	8.7	4.9	-	-28	0.103
		9	23.1	20.5	4.5	4.4	0.05	-92	0.231
		11	25.0	24.0	5.2	1.9	0.10	-62	0.179
	3	22.7	13.6	7.3	-	0.11	-45	0.178	
D	1969	5	8.9	64.1	15.3	14.0	0.33	-	-
		7	10.0	64.9	8.6	22.0	-	-235	0.371
		9	8.9	65.5	13.6	9.6	0.40	-323	0.309
		11	12.0	49.0	7.8	8.9	0.40	-167	0.351
	3	10.0	49.0	9.5	-	0.09	-173	0.369	
E	1969	5	7.9	76.9	15.5	19.4	0.40	-	-
		7	7.8	88.8	14.2	29.6	-	-351	0.327
		9	7.9	86.7	14.0	14.5	0.43	-363	0.398
		11	8.0	89.0	13.2	23.8	0.46	-318	0.409
	3	8.0	66.0	14.9	-	0.39	-373	0.579	
Average			13.3	54.1	10.3	13.2	0.30	-222	0.360

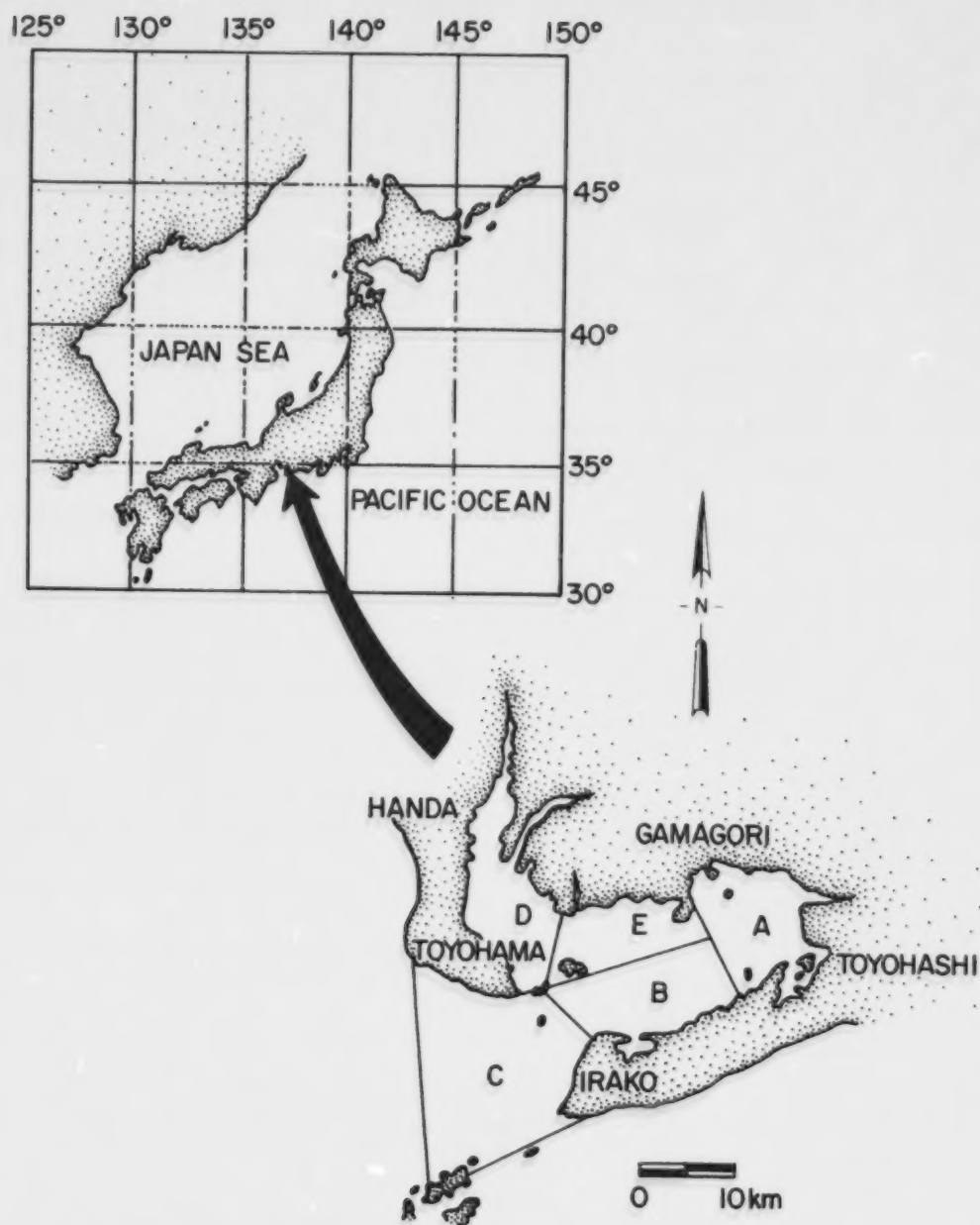


Figure 1. The five sampling areas (Regions) in Mikawa Bay.

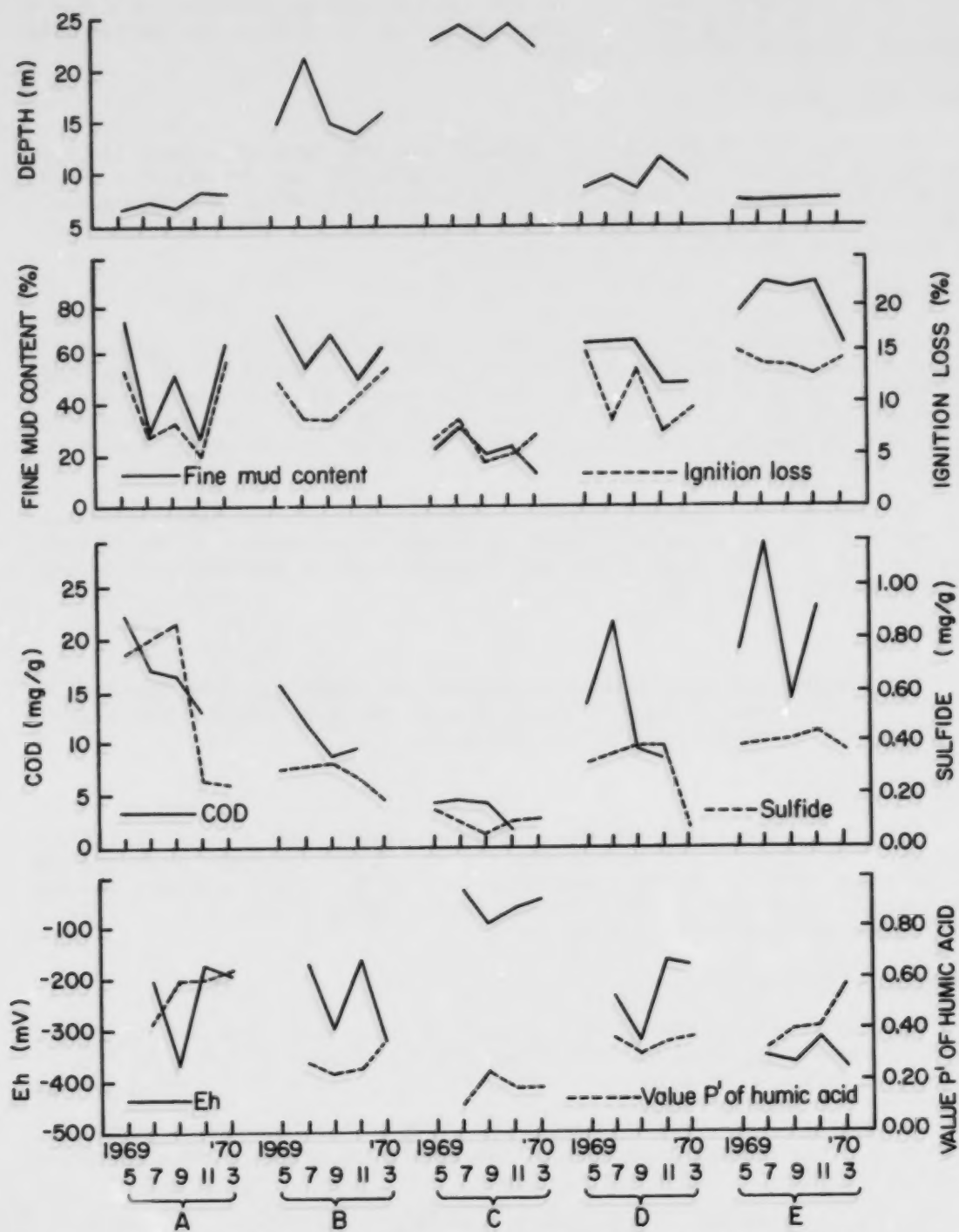


Figure 2. Changes of sediment quality in each region.

(0.53 mg/g average). The order of the regions was approximately $C < B < D < E < A$, and in the A and B regions some trends of gradual decline could be observed, though not in other regions.

Redox Potential (Eh)

From -373 to -28 mV (-222 mV average) was the range throughout the bay. The lowest range of -373 to -318 mV (-351 average) was in region E, while region C has a range of -92 to -28 mV (-57 mV average) which was comparatively high. The order was approximately $E < B < A < D < C$. In September, lower values could be observed.

Humic acid (P')*

Over the entire Bay 0.103 to 0.627 (0.360 average) was the range of P'. Region C had the lowest range of values of 0.103 to 0.231 (0.173 average). The highest range of 0.430 to 0.627 (0.563 average) was observed in Region A. The order here was approximately $C < B < D < E < A$ and in the A and E regions a gradual increasing trend was observed. No transitional changes were observed in other regions.

In summary, the sediment quality suggested that the sediments in or near the mouth of the bay (region C) were relatively unpolluted. In the northern central part or inner part of the bay (Regions E and A) the degree of organic sediment pollution was high.

THE BENTHOS

The habitat and distribution of benthos in Mikawa bay from May 1969 to March 1970 is shown in Table 2 and Figure 3 for each region. The general condition of the benthos is summarized below.

Number of Species

Over all regions the number of species ranged from 1.6 to 25.5 (13.5 average). In region E, it ranged from 2.5 to 7.0 (5.1 average) which was the lowest range of all. Region C was from 19.1 to 25.5 (22.0 average) and was the highest range. The regions can be ordered approximately as $E < A < B < D < C$. No seasonal changes were observed.

Number of Individuals

Over all regions the number of individuals ranged from 2.8 to 1625.2 (47.4 average). Region E had the lowest range of values at 2.8 to 65.3 (27.1 average). Region A had values of 16.0 to 1625.2 (368.8 average) which was the

* Humic acid is measured throughout the paper by the P' value of humic acid developed by the author (Reference 5). This value is based on the absorbances at 380, 410, 440 mμ in the following equation

$$P' = \left(\frac{\log K_{380} - \log K_{410}}{410 - 380} \right) / \left(\frac{\log K_{410} - \log K_{440}}{440 - 410} \right).$$

TABLE 2. BENTHIC COMMUNITY CHARACTERISTICS (average).

TABLE 2. BENTHIC COMMUNITY CHARACTERISTICS

Region	Item Time	Number of species	Number of individuals	Biotic index (NIS)	Wet weight (g)	Polychaeta (%)	Mollusca (%)	Crustacea (%)	Others (%)
A	1969	5	1625.2	142.6	29.0	16.6	77.5	3.0	2.9
		7	59.6	4.7	2.6	88.7	3.3	0.1	7.9
	1970	9	16.0	10.0	0.1	100.0	0.0	0.0	0.0
		1	92.2	10.0	3.3	87.9	9.9	0.2	2.0
		3	51.0	7.5	1.4	54.3	42.5	0.7	2.5
B	1969	5	24.0	2.2	4.2	48.4	32.3	6.5	12.8
		7	60.7	3.8	4.8	68.0	13.1	8.4	10.5
	1970	9	24.4	3.1	1.5	60.9	23.1	4.1	11.9
		11	59.9	3.4	3.8	69.4	13.5	6.7	10.4
		3	16.6	1.8	8.1	53.9	17.4	11.8	16.9
C	1969	5	61.1	2.9	3.0	59.7	5.2	26.0	9.1
		7	73.6	2.9	13.1	66.0	14.6	13.2	6.2
	1970	9	49.7	2.5	2.9	56.5	8.3	27.2	8.0
		11	40.5	2.1	3.6	52.5	10.1	31.1	6.3
		3	62.3	2.5	10.6	64.8	7.6	20.0	7.6
D	1969	5	89.7	3.9	14.9	71.4	9.2	7.7	11.7
		7	62.7	3.5	30.3	68.7	16.7	1.4	13.2
	1970	9	55.0	3.4	10.7	77.4	10.3	0.3	12.0
		11	49.7	2.2	4.0	66.3	7.1	10.2	16.4
		3	54.0	3.4	9.1	70.8	3.4	13.1	12.7
E	1969	5	14.3	2.3	4.6	30.4	34.6	2.9	32.1
		7	2.8	1.1	9.0	27.8	61.1	5.5	5.6
	1970	9	14.3	5.1	4.9	95.7	4.3	0.0	0.0
		11	65.3	9.3	3.1	73.5	17.4	7.4	1.7
		3	38.8	5.7	4.1	63.3	35.2	0.0	1.5
Average		13.5	47.4	9.7	6.6	65.7	16.7	8.5	9.1

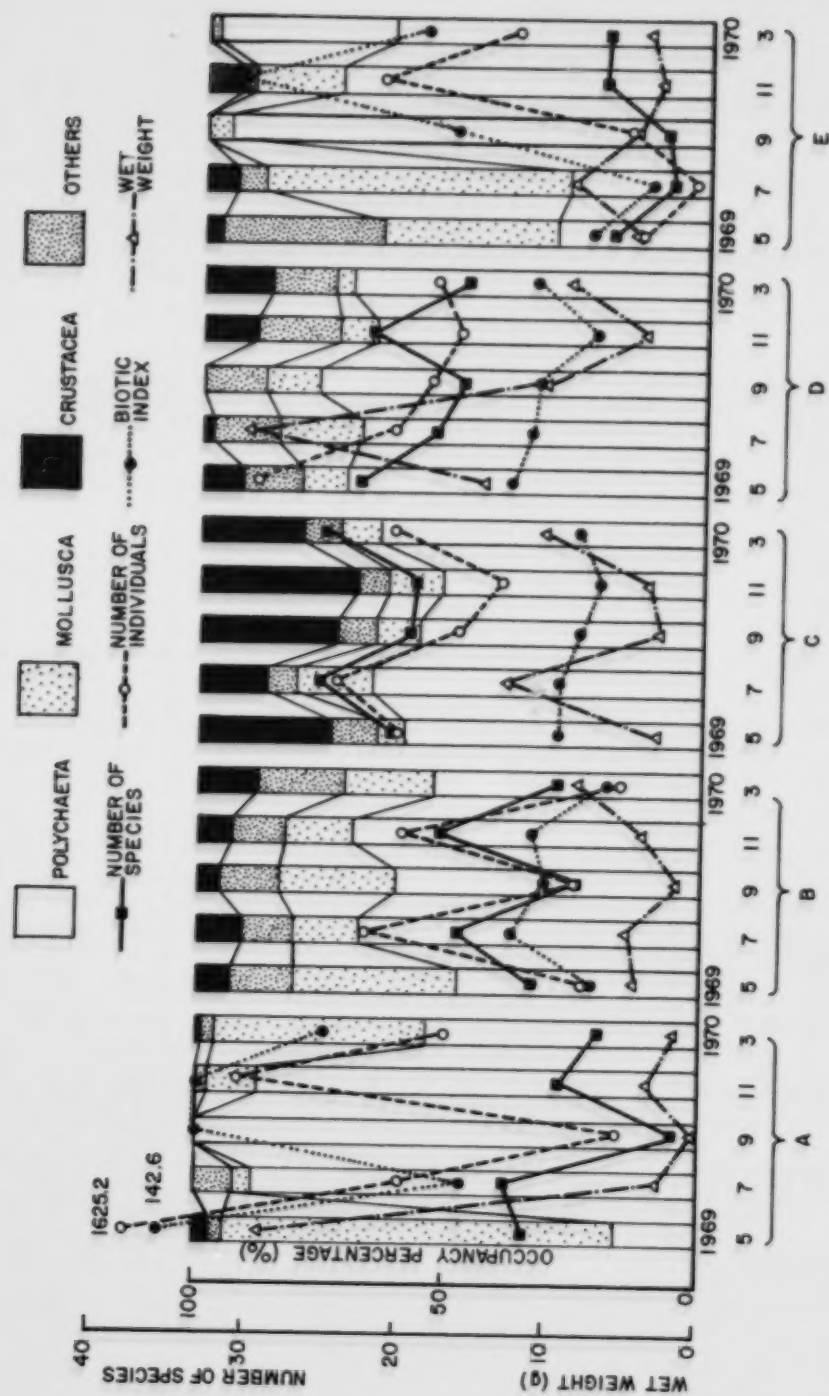


Figure 3. Changes of benthos in each region.

highest range because of the influence of an abnormal number of Musculus senhousia in May 1969. The regions can be ordered approximately as $E < B < C < D < A$. No seasonal changes were observed in any of the regions.

N-S Ratio (Number of individuals/Number of species)

A range of 1.1 to 142.6 (9.7 average) was observed over the entire area. Region A, on account of the abnormal numbers of mollusks in May 1969, showed very high values of 4.7 to 142.6 (35.0 average). The average range was 2.6 to 4.7 in other regions, with region C showing the lowest range of values at 2.1 to 2.9 (2.6 average). The regions can be ordered approximately as $C < B < D < E < A$. No trends or seasonal changes were observed in any of the regions.

Wet Weight

Over the entire area the range was 0.1 to 30.3 g (6.6 average). Region B showed the lowest range of values at 1.5 to 8.1 g (4.5 g average). Region D showed the highest range at 4.0 to 30.3 g (13.8 g average). In the regions C, D and E a trend of higher values in July was observed, however, no trends or seasonal changes were observed in other regions.

Percent Polychaetes

The range was 16.6 to 100.0% (65.9% average) for the entire bay. The highest range of values was in region D, 66.3 to 77.4% (70.9% average). Region E showed the lowest range at 27.8 to 95.7% (58.1% average). All the regions can be ordered approximately as $E < C < B < A < D$, and no trends or seasonal changes were observed in any of the regions. However, a characteristic feature was that high values of 87.9 to 100.0% were observed in region A from July to November in 1969, and in region E in September 1969.

Percent Mollusks

A range of 0.0 to 77.5% (16.7% average) was found in the bay. Regions C and D showed low values of 5.2 to 14.6% (9.2% average) and 3.4 to 16.7% (9.3% average) respectively. The high range of values of 4.3 to 35.2% (30.5% average) was observed in region E. All the regions can be ordered approximately as $C < D < B < A < E$. No trends or seasonal changes were observed in any of the regions. However, region A showed a very high value of 77.5% in May 1969 when an abnormal number of Musculus senhousia appeared and, in the same year, region A showed an abnormally low value of 0.0% in September.

Percent Crustacea

Over the whole bay the range was 0.0 to 31.1% (8.5% average). A contrast was noticeable between regions A and C. The former showed the lowest range of values with 0.0 to 3.0% (0.8% average) and the latter showed the highest range at 13.2 to 31.1% (23.5% average). The regions can be ordered approximately as $A < E < D < B < C$ with no seasonal trend observed. However, quite low values of less than 1.0% were observed in region A from September 1969 to March 1970, in region D in September 1969 and in region E in September 1969 and March 1970.

Percent Other Species

The range over all regions was 0.0 to 32.1% (9.1% average). The lowest was observed in region A at 0.0 to 7.9% (3.1% average). Regions B and D had comparatively high values ranging from 10.4 to 16.9% and 11.7 to 16.4% with averages of 12.5% and 13.2%, respectively. The order of the regions was approximately $A < C < E < B < D$, and no trend or seasonal change was observed in any of the regions. The highest value of 32.1% was observed in region E in May 1969 which contrasted with regions A and E where a 0.0% value was observed in September of the same year.

Predominant Species

Table 3 gives the five predominant benthic species at each time and for each region. Lumbrinereis brevicirra, Prionospio pinnata (polychaeta), Musculus senhousia, Theora lata, Raeta pulchella (molluska) Amphipoda (crustacea) and Ophiuroidea actinia (other species) were in general the most predominant ones as shown in Table 3. The differences between regions were much more remarkable than the differences over time. The results given in Table 3 are for regions A to E as follows:

In region A molluska such as Musculus senhousia, Theora lata, Raeta pulchella, were observed as predominant species together with polychaetes such as Lumbrinereis brevicirra, Prionospio pinnata and others in May 1969 and March 1970. During the period from July to November 1969 the predominant species were polychaetes such as Lumbrinereis brevicirra, Prionospio pinnata.

In region B, no characteristic species were recognized. In general, polychaetes such as Lumbrinereis brevicirra, Goniada sp., molluska such as Theora lata, Petrasma pussila, crustacea such as Amphipoda, and other species such as Ophiuriidae were observed predominantly.

Region C showed the predominance of crustacea such as Amphipoda followed by polychaetes such as Paralacydonia paradoxa japonica, Scoloplos sp. except that in July 1969 Amphipoda was ranked second.

In region D, other species such as Ophiuriidae, Niotha livescens (molluska) and Amphipoda (crustacea) were predominant in May 1969. However polychaeta such as Lumbrinereis brevicirra and Cirriiformia tentaculata, were predominant.

In region E, predominant species were mostly polychaetes such as Prionospio pinnata, Lumbrinereis brevicirra in company with a molluska such as Scapharca subcrenata. This was in July and September 1969. However, in May, November 1969 and March 1970, molluska such as Raeta pulchella, Theora lata and polychaeta such as Prionospio pinnata and Ancistrocyllis hanaokai, were predominant.

Looking only at polychaete species there is a remarkable difference between regions A, B, D, E and region C which is shown in Table 4.

TABLE 3. PREDOMINANT BENTHIC SPECIES (1)

Region	Priority ranking Time	1	2	3	4	5
A	1969	5	Musculus senhousia (M)	Amphipoda (C)	Theora lata (M)	Raeta pulchella (M)
	7	Lumbrineris brevicirra (P)	Paraonis sp. (P)	Tharyx sp. (P)	Ophiuroidea (O)	Lumbrineris brevicirra (P)
	9	Prionospio pinnata (P)	Lumbrineris brevicirra (P)	Owenia fusiformis (P)	--	Ancistrosyllis hanaokai (P)
	11	Prionospio pinnata (P)	Lumbrineris brevicirra (P)	Lagis bocki naikaiensis (P)	Neanthes oxypoda (P)	--
	1970	3	Theora lata (M)	Raeta pulchella (M)	Neanthes oxypoda (P)	Nephtys caeca (P)
B	1969	5	Goniada sp. (P)	Theora lata (M)	Lumbrineris brevicirra (P)	Lagis bocki naikaiensis (P)
	7	Lumbrineris brevicirra (P)	Amphipoda (C)	Goniada sp. (P)	Spiophanus bombyx (P)	Raeta pulchella (M)
	9	Ophiuroidea (O)	Lumbrineris brevicirra (P)	Brachyura (C)	Petrasma pusilla (M)	Spiophanus bombyx (P)
	11	Lumbrineris brevicirra (P)	Stauronereis rudolphi (P)	Ophiuroidea (O)	Theora lata (M)	Petrasma pusilla (M)
	1970	3	Eumida sanguinia (P)	Amphipoda (C)	Paralacodonia paradoxa japonica (P)	Amphipoda (C)
C	1969	5	Amphipoda (C)	Paralacodonia paradoxa japonica (P)	Notomastus sp. (P)	Lagis bocki naikaiensis (P)
	7	Paralacodonia paradoxa japonica (P)	Amphipoda (C)	Scoloplos sp. (P)	Scoloplos sp. (P)	Goniada sp. (P)
	9	Amphipoda (C)	Paralacodonia paradoxa japonica (P)	Scoloplos sp. (P)	Aricia sp. (P)	Spiophanus bombyx (P)
	11	Amphipoda (C)	Paralacodonia paradoxa japonica (P)	Macrura (C)	Actiniaria (O)	Nephtys ciliata (P)
	1970	3	Amphipoda (C)	Paralacodonia paradoxa japonica (P)	Spiophanus sp. (P)	Echiuroidae (O)
D	1969	5	Ophiuroidea (O)	Niotha livescens (M)	Amphipoda (C)	Eumida sanguinia (P)
	7	Cirriiformia tentaculata (P)	Theora lata (M)	Lumbrineris brevicirra (P)	Nephtys caeca (P)	Prionospio krusadensis (P)
	9	Lumbrineris brevicirra (P)	Cirriiformia tentaculata (P)	Owenia fusiformis (P)	Flabelligeridae sp. (P)	Chone sp. (P)
	11	Lumbrineris brevicirra (P)	Owenia fusiformis (P)	Cirriiformia tentaculata (P)	Flabelligeridae sp. (P)	Sternaspis scutata (P)
	1970	3	Lumbrineris brevicirra (P)	Eunice indica (P)	Actiniaria (O)	Echiuroidae (O)
					Chaetozone sp. (P)	Actiniaria (O)

(continued)

TABLE 3. (continued)

Region	Priority ranking Time	1	2	3	4	5
E	1969 5	Apoda (O)	Goniada sp. (P)	Raeta pulchella (M)	Theora lata (M)	Anaitides maculata (P)
	7	Prionospio pinnata (P)	Macoma tokyoensis (M)	Lumbrineris brevicirra (P)	Terebellides sp. (P)	Scapharca subcrenata (M)
	9	Priorospio pinnata (P)	Lumbrineris brevicirra (P)	Nephtys polybranchia (P)	Cirriiformia tentaculata (P)	Scapharca subcrenata (M)
	11	Prionospio pinnata (P)	Theora lata (M)	Brachyura (C)	Ancistrosyllis hanaokai (P)	Telepsavus costarum (P)
	1970 3	Prionospio pinnata (P)	Theora lata (M)	Ancistrosyllis hanaokai (P)	Neanthes oxypoda (P)	Raeta pulchella (M)

(P): Polychaeta (M): Mollusks (C): Crustacea (O): Others

TABLE 4. PREDOMINANT BENTHIC SPECIES (2) (Polychaeta)

Priority ranking		1		2		3	
Region	Time						
A	1969	5	Lumbrinereis brevicirra	Prionospio pinnata	Ancistrocyllis hanaokai	Tharyx sp.	Ancistrocyllis hanaokai
		7	Lumbrinereis brevicirra				
		9	Prionospio pinnata				
		11	Prionospio pinnata				
B	1970	3	Prionospio pinnata	Lumbrinereis brevicirra	Neanthes oxypoda	Lumbrinereis brevicirra	Lumbrinereis brevicirra
		5	Goniada sp.				
		7	Lumbrinereis brevicirra				
		9	Lumbrinereis brevicirra				
C	1970	11	Lumbrinereis brevicirra	Stauronereis rudolphi	Paralacidorina paradoxa japonica	Spiophanus bombyx	Spiophanus bombyx
		3	Eumida sanguinea				
		5	Paralacidorina paradoxa japonica				
		7	Paralacidorina paradoxa japonica				
D	1969	9	Paralacidorina paradoxa japonica	Scoloplos sp.	Scoloplos sp.	Aricia sp.	Aricia sp.
		11	Paralacidorina paradoxa japonica				
		3	Paralacidorina paradoxa japonica				
		5	Nephtys caeca				
E	1970	7	Cirriformia tentaculata	Prionospio krusadensis	Lumbrinereis brevicirra	Flabelligeridae sp.	Lumbrinereis brevicirra
		9	Lumbrinereis brevicirra				
		11	Lumbrinereis brevicirra				
		3	Lumbrinereis brevicirra				
E	1969	5	Goniada sp.	Anaitides maculata	Lumbrinereis brevicirra	Ancistrocyllis hanaokai	Ancistrocyllis hanaokai
		7	Prionospio pinnata				
		9	Prionospio pinnata				
		11	Prionospio pinnata				
E	1970	3	Prionospio pinnata	Ancistrocyllis hanaokai	Ancistrocyllis hanaokai	Terebellides sp.	Terebellides sp.
		5	Goniada sp.				
		7	Prionospio pinnata				
		9	Prionospio pinnata				
E	1970	11	Prionospio pinnata	Ancistrocyllis hanaokai	Ancistrocyllis hanaokai	Telepsavus costarum	Telepsavus costarum
		3	Prionospio pinnata				
		5	Goniada sp.				
		7	Prionospio pinnata				
E	1970	9	Prionospio pinnata	Ancistrocyllis hanaokai	Ancistrocyllis hanaokai	Neanthes oxypoda	Neanthes oxypoda
		11	Prionospio pinnata				
		3	Prionospio pinnata				
		5	Goniada sp.				

This meant that in region C Paralacidonia paradoxa japonica, Scolplos sp. and others were predominant, and Lumbrinereis brevicirra, Prionospio pinnata were scarcely observed. In all the other regions the characteristic feature was that Lumbrinereis brevicirra and Prionospio pinnata were predominant. Also, Lagis bocki naikaiensis in region A, Gonaida sp., Spiophanus bombyx in region B, Notomastus sp. in region C, Cirriformia tentaculata in region D, and Ancistrocyllis hanaokai in region E were observed as subdominant species.

In summary, in the polluted inner part of the bay polychaetes such as Lumbrinereis brevicirra, Prionospio pinnata and molluska such as Theora lata were usually dominant. In the bay mouth the degree of sediment pollution was not so great and crustacea such as Amphipoda were dominant.

THE RELATIONSHIP BETWEEN SEDIMENT QUALITY AND BENTHOS

In accordance with the results of the studies quoted some further studies were carried out on the relationship between sediment quality and benthos in Mikawa bay by using the following method.

Results of Correlation Analyses

Cross-correlations were determined between two groups of data. The first group consists of water depth, sediment quality parameters such as fines content, ignition loss, COD, sulfide, redox potential (Eh), and P' for humic acid. The second group consists of biotic variables such as number of species, number of individuals, S-N ratio, wet weight, percentage of genera in the population (polychaeta, molluska, crustacea and others), dominant species of polychaetes and mollusks (Lumbrinereis brevicirra, Paralacidonia paradoxa japonica, Theora lata, etc).

All correlations with r values higher than 0.600 are shown in Table 5. Except for ignition loss all the sediment quality factors were correlated to a certain extent with species numbers and percent crustacea. In particular, high correlations were observed between water depth and percent crustacea ($r = 0.839$), and between redox potential and species number ($r = 0.844$).

Two other high correlations were observed for the physical factors. They were the one between the humic acid and P' value and the N-S ratio ($r = 0.756$), and between redox potential and number of individuals ($r = 0.609$).

A few correlations were also observed between the physical factors and some polychaetes. Between water depth and Paralacidonia paradoxa japonica and Scolplos sp., and between redox potential and Paralacidonia paradoxa japonica the r values were 0.811, 0.757 and 0.753, respectively.

Sediment Pollution Index (SPI)

a. Primary Sediment Pollution Index (PSPI)

We feel that the relationship between sediment quality and the benthos can be clarified by making use of an index which includes the results of research and analysis on sediments. This index is called the Primary Sedi-

TABLE 5. RESULTS OF CORRELATIVE ANALYSIS ($r \geq 0.600$).

x	y	Correlation formula	Correlation coefficient (r)	$\bar{x}$	$\bar{y}$	Standard deviation of x	Standard deviation of y
Depth	Species	$y = 0.742x + 3.612$	0.653	13.308	13.487	6.373	7.246
Depth	Crustacea	$y = 1.189x - 7.306$	0.839	13.308	8.521	6.373	9.036
Fine mud content	Species	$y = -0.213x + 25.016$	-0.653	54.071	13.487	22.192	7.246
Fine mud content	Crustacea	$y = -0.253x + 22.193$	-0.621	54.071	8.521	22.192	9.036
COD	Species	$y = -0.669x + 22.524$	-0.648	13.232	13.674	7.080	7.305
COD	Crustacea	$y = -0.846x + 19.558$	-0.640	13.232	8.363	7.080	9.352
Sulfide	Species	$y = -23.469x + 20.222$	-0.600	0.304	13.095	0.182	7.125
Sulfide	Crustacea	$y = -36.149x + 20.236$	-0.677	0.304	9.258	0.182	9.724
Eh	Species	$y = 0.055x + 25.443$	0.844	-222.250	13.115	110.367	7.257
Eh	Individuals	$y = 0.122x + 74.522$	0.609	-222.250	47.455	110.367	22.076

(continued)

TABLE 5. (continued)

x	y	Correlation formula	Correlation coefficient (r)	$\bar{x}$	$\bar{y}$	Standard deviation of x	Standard deviation of y
Eh	Crustacea	$y = 0.056x + 20.555$	0.690	-222.250	8.070	110.367	8.982
Humic acid (P')	Species	$y = -34.172x + 25.403$	-0.690	0.360	13.115	0.146	7.257
Humic acid (P')	N-S ratio	$y = 13.743x - 0.542$	0.756	0.360	4.400	0.146	2.662
Humic acid (P')	Crustacea	$y = -40.601x + 22.670$	-0.662	0.360	8.070	0.146	8.982
Depth	Paralacidonina paradoxa japonica	$y = 3.292x - 29.567$	0.811	13.308	14.250	6.373	25.862
Depth	Scolplos sp.	$y = 1.203x - 10.883$	0.757	13.308	5.125	6.373	10.121
Fine mud content	Paralacidonina paradoxa japonica	$y = -0.783x + 56.605$	-0.672	54.071	14.250	22.192	25.862
Fine mud content	Scolplos sp.	$y = -0.316x + 22.219$	-0.693	54.071	5.125	22.192	10.121
COD	Paralacidonina paradoxa japonica	$y = -2.294x + 44.559$	-0.622	13.232	14.211	7.080	26.086
COD	Scolplos sp.	$y = -0.942x + 17.938$	-0.621	13.232	5.474	7.080	10.748

(continued)

TABLE 5. (continued)

x	y	Correlation formula	Correlation coefficient (r)	$\bar{x}$	$\bar{y}$	Standard deviation of x	Standard deviation of y
Eh	Paralacidonia paradoxa japonica	$y = 0.151x + 45.722$	0.753	-222.250	12.250	110.367	21.929
Eh	Scoloplos sp.	$y = 0.056x + 17.007$	0.655	-222.250	4.650	110.367	9.372
Humic acid (p')	Paralacidonia paradoxa japonica	$y = -102.076x + 48.956$	-0.682	0.360	12.250	0.146	21.929

ment Pollution Index (PSPI) and is designed to have values from 1-5, where a high value represents extreme pollution.

Research data in Mikawa bay and other shallow seas or bays, were combined and for each physical factor of sediment quality an index value was set so that normal sediments have lower values and more polluted sediments have higher values. These are shown in Table 6. For the fines content, the PSPI has a value of 1 to 2 for normal sediments, a value of 3 for eutrophic sediments, a value of 4 for an excessively enriched sediment and a value of 5 for polluted sediments. Similar values were assigned for the other sediment quality parameters, and are given in Table 6.

b. Sediment Pollution Index (SPI)

The purpose of the PSPI was to standardize all the sediment quality parameters so they varied over the same range. Once this was done the different parameters could be combined to define a single index, called the Sediment Pollution Index, which could then be related to the benthic biota associated with specific areas of the sea floor.

The SPI is determined in a graphical manner. For example, in May 1969 four parameters of sediment quality were measured: fines, ignition loss, COD, and sulfide. These are plotted on four radial axes (see Figure 4). Each axis is divided into five equal segments to account for the five possible PSPI values. Essentially, the diagram is in n standardized variables, plotted on n radial coordinates. The PSPI values at which each measure is deemed to change from normal to eutrophic, eutrophic to excessively enriched, and excessively enriched to polluted is determined and a line is drawn connecting each of the respective points. Thus, the final diagram is a series of nested polygons. The area of the inner polygon represents the SPI value for a normal sediment. The area of the second polygon represents the SPI value for a eutrophic sediment, and similarly for enriched and polluted sediments.

To determine the SPI of a region simply find the particular polygon for that region as defined by its PSPI values and determine its area. The SPI value will fall into one of the ranges defined in Table 7 and shown in Figure 4, so that it may be determined as normal, eutrophic, excessively enriched, or polluted.

In the same way, the results of the sampling program of July, 1969 are summarized as a series of nested pentagons, since only five variables were measured. The research in September and November 1969 measured six variables, thus a hexagonal series was drawn. The 1970 series is represented again by a pentagon.

c. Changes in SPI

Table 8 and Figure 5 show the changes in SPI obtained for regions A, B, C, D and E during the period from May 1969 to March 1970. In region C, except for the research conducted in July 1969, the results showed a normal SPI—revealing the region to possess clean sediments. Region E was excessively enriched for the entire period, showing it to be quite polluted. Region A

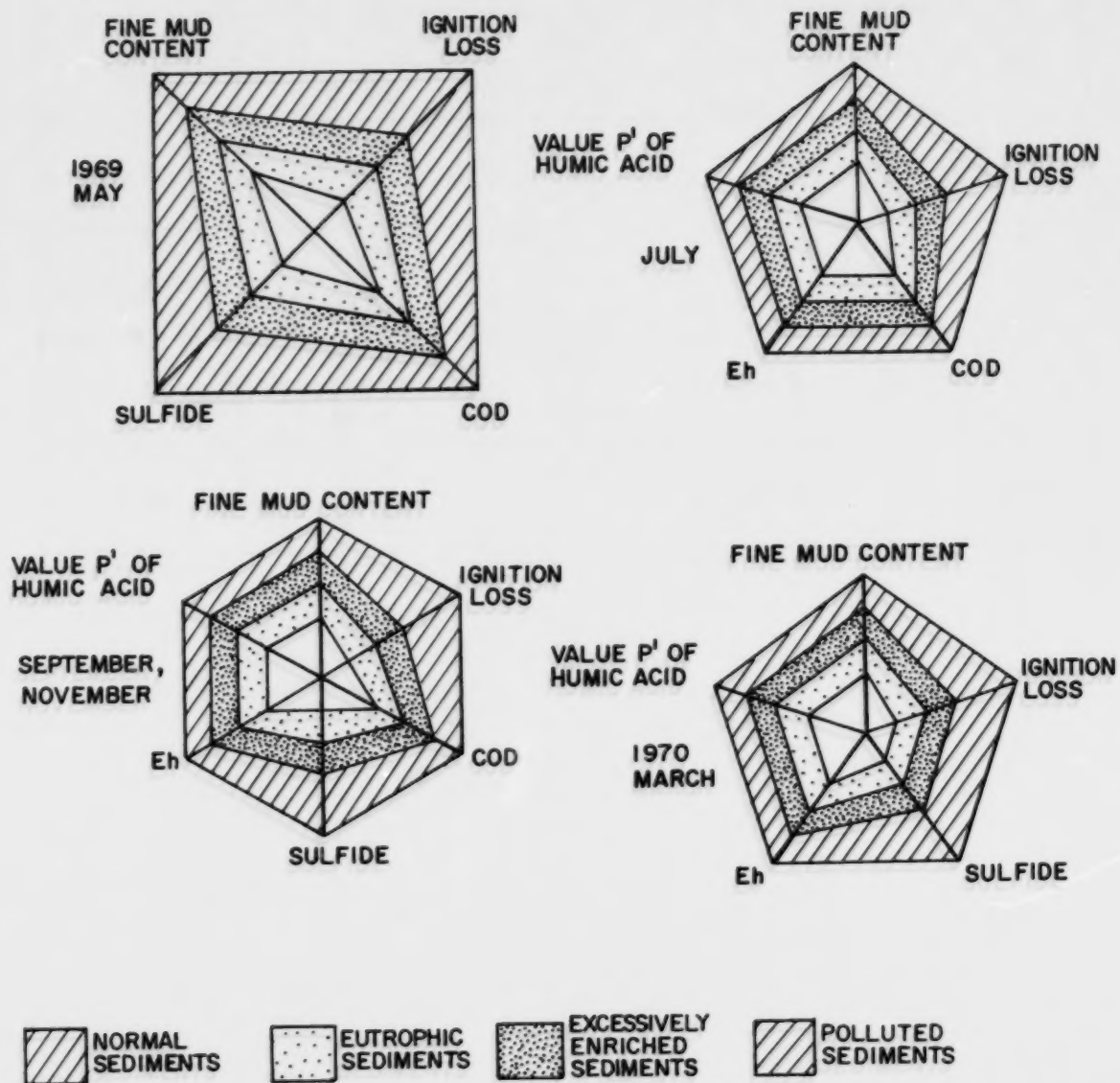


Figure 4. Schematic diagrams of SPI for varying degrees of sediment pollution and for every sampling period.

TABLE 7. SPI FOR VARYING DEGREES OF SEDIMENT POLLUTION AND FOR EVERY SAMPLING PERIOD.

Year/Month	Normal area	Eutrophic area	Excessively enriched area	Polluted area
1969 5	< 4.00	4.01 ∫ 12.00	12.01 ∫ 24.00	> 24.01
7	< 7.60	7.61 ∫ 18.54	18.55 ∫ 34.23	> 34.24
9	< 6.92	6.93 ∫ 18.18	18.19 ∫ 34.65	> 34.65
11	< 6.92	6.93 ∫ 18.18	18.19 ∫ 34.64	> 34.65
1970 3	< 6.18	6.19 ∫ 16.16	16.17 ∫ 30.90	> 30.91

TABLE 8. SPI IN EACH REGION.

Region	Time		SPI	Average
	Year	Month		
A	1969	5	24.000	18.497
		7	16.167	
		9	23.382	
		11	10.392	
	1970	3	18.545	
B	1969	5	14.000	13.745
		7	13.314	
		9	13.856	
		11	9.959	
	1970	3	17.594	
C	1969	5	3.000	5.341
		7	7.608	
		9	4.763	
		11	5.629	
	1970	3	6.706	
D	1969	5	15.000	15.702
		7	20.922	
		9	18.619	
		11	12.557	
	1970	3	11.412	
E	1969	5	21.000	24.690
		7	30.432	
		9	23.382	
		11	27.712	
	1970	3	20.922	

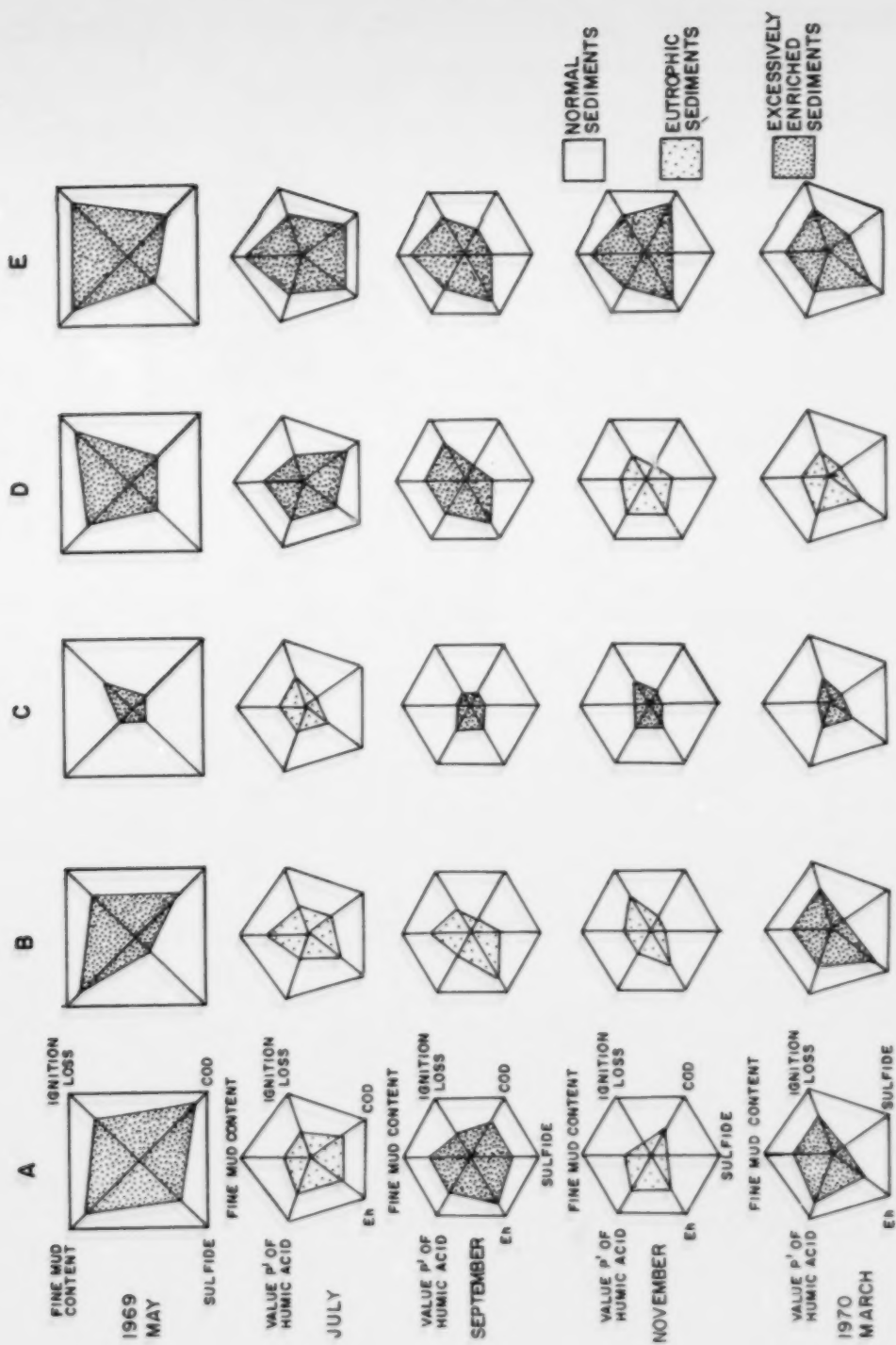


Figure 5. Changes in SPI for each region by sampling period.

showed an SPI which classified it as excessively enriched in the research carried out in May and September 1969 and in March 1970 the same region was classed eutrophic in the research of July and November 1969. The D region, like the A region, showed values of excessively enriched sediments in May to September 1969, which decreased to eutrophic values in November 1969 and March 1970. Region B, which showed as excessively enriched in November 1969 and March 1970, had SPI that represented eutrophic sediments in the research conducted from July to November 1969.

d. Relationship of SPI and benthos

As discussed in the analysis section, a number of sediment quality parameters were found to be significantly correlated with certain of the benthic biological parameters. The authors feel that individual sediment quality factors cannot adequately define the habitat and distribution of the benthic organisms. Therefore the SPI, which is a synthesis of several sediment quality indices, when correlated with benthic biological parameters, should indicate a closer relationship than individual parameters. Results of these analyses have indicated the following two significant correlations: Between SPI and species number: $y = -0.775x + 25.301$ ($r = -0.765$, $x = 15.245$, $y = 13.487$, standard deviation of $x = 7.150$, standard deviation of $y = 7.246$), and between SPI and percent crustacea: $y = -0.903x + 22.292$ ($r = -0.715$, $x = 15.245$, $y = 8.521$, standard deviation of $x = 7.150$, standard deviation of $y = 9.036$). These are shown in Figure 6.

For the relationship between SPI and species number approximately 22 species were observed in the normal area. In the eutrophic area were 11 to 21 species, in the excessively enriched area were 7 to 10 species, and in the polluted area were less than 6 species.

For the correlation between SPI and percent crustacea the normal area had 19 percent crustacea, the eutrophic area had from 6 to 18%, the excessively enriched area had 2 to 5%, and the polluted area had less than 1%.

Correlations between SPI and other measures on the benthos had correlation coefficients less than 0.500. In addition, correlations were run between SPI and certain dominant species.

Where sediment pollution is advanced, the predominant species found are often Theora lata (molluska), and Lumbrinereis brevicirra and Prionospio pinnata (polychaete), but the correlation analyses showed correlation coefficient values of less than 0.250, so no correlations were found between SPI and these organisms.

But, in the bay mouths where sediment pollution is slight, the dominant species are often Paralacidonia paradoxa japonica and Scolplos sp. Between SPI and these two species there have been observed negative correlations as follows: Between SPI and Paralacidonia paradoxa japonica: $y = -2.500x + 52.357$ ($r = -0.691$, $x = 15.245$, $y = 14.250$, standard deviation of $x = 7.150$, standard deviation of $y = 25.862$), and between SPI and Scolplos sp.: $y = -0.971x + 19.923$ ($r = -0.686$, $x = 15.245$, $y = 5.125$, standard deviation of $x = 7.150$, standard deviation of $y = 10.121$).

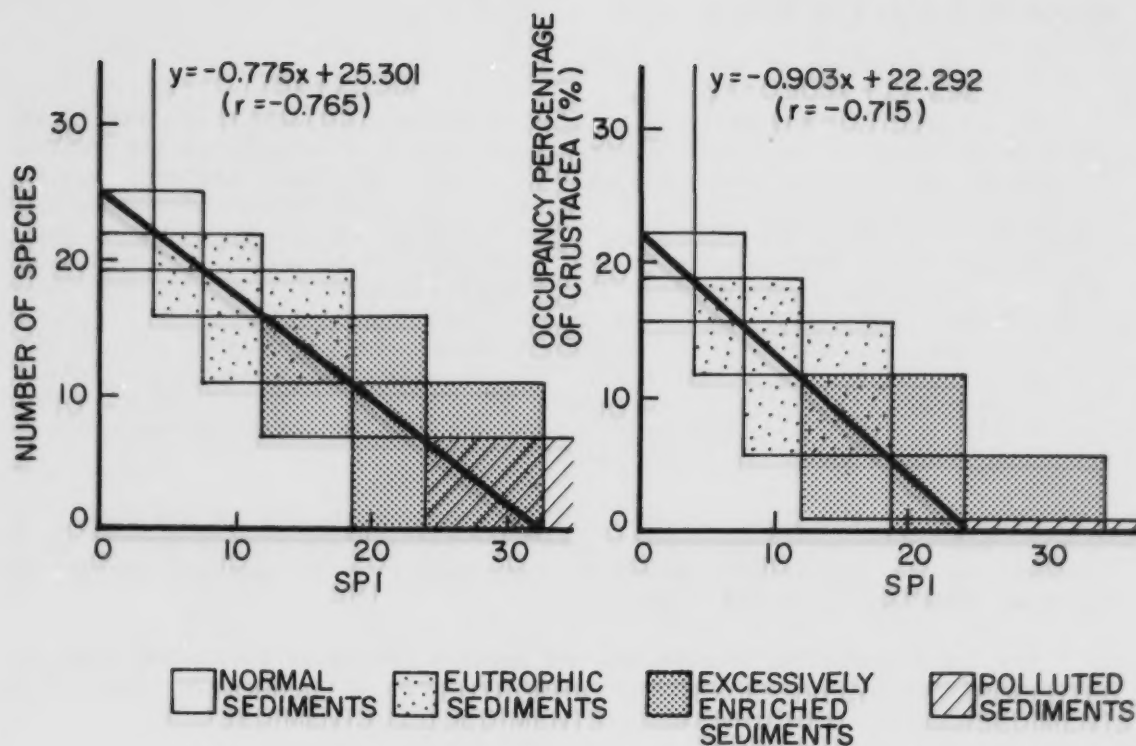


Figure 6. Relationship between SPI and number of species, and percentage of crustacea.

CONCLUSIONS AND DISCUSSION

The results have indicated some correlations between physical factors such as water depth, fines content, COD, sulfide, redox potential, humic acid, sediment pollution index (SPI) and benthic biotic factors such as species numbers and predominant species.

It is suggested that the SPI could be an indicator which would show the degree of sediment pollution, and in accordance with this concept the authors hope that SPI could be applied as a standard criterion for making decisions on removal of organically polluted sediments from the sea bottom.

These conclusions may not apply to other inner bays or shallow seas, but future studies should be made in these and other areas and also include new factors such as sea water and plankton measurements. More research and analysis in different areas will add to the stock of data and lead to development of guidelines for conservation and improvement of the marine environment.

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A HYDRODYNAMIC STUDY OF LAKE POLLUTION

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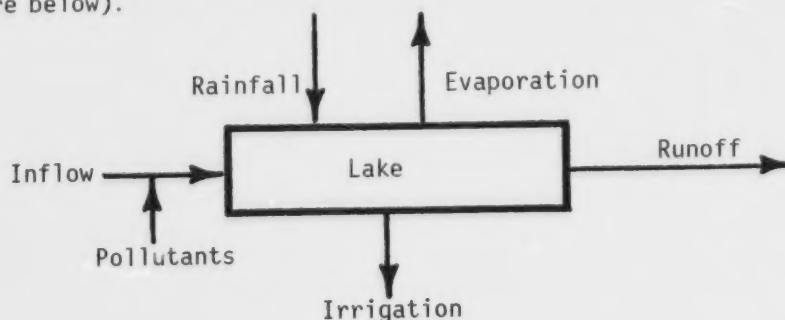
SUMMARY

The serious problem of lake pollution confronts Japan as well as other countries. It is over ten years since Lake Suwa first experienced heavy algal blooms and now other lakes such as Biwako, Kasumigaura, Yunoko, and Nakaumi are also in urgent need of reclamation.

Since most lakes are primarily polluted by organic wastes of domestic or industrial origin, the pollution problems of lakes have been investigated in terms of the chemical and ecological effects of these pollutants. These effects are determined in part by the hydrodynamic functions of lakes so a hydrostatic study alone would be of little significance. The purpose of this paper is to describe and explain the hydrodynamic function of lakes, and then to pursue the relationship to organic pollution.

A MATHEMATICAL MODEL OF A LAKE

Lakes and marshes are natural reservoirs. Runoff water from the mountains flows into them, and after an interval of residence time it flows out via connecting rivers. Meanwhile, the quantity of water in the lake is equilibrated by means of rainfall, evaporation from the surface and other inputs and losses (see figure below).



In the past the only solids added to the lake were natural sediments transported by rivers. But with the advance of civilization, materials from factories and domestic sources began to cause pollution.

In studying the behavior of solid pollutants in lake water, conservation and non-conservative properties must be accounted for. Let decomposition from oxidation be the only non-conservative property, then we get an equation for the motion of solid particles in lake water as follows:

$$\frac{\partial c}{\partial t} + v \frac{\partial c}{\partial x} + u \frac{\partial c}{\partial z} = K_x \frac{\partial^2 c}{\partial x^2} + K_z \frac{\partial^2 c}{\partial z^2} - kc \quad (1)$$

where:

c = concentration of suspended solids

v = flow velocity of lake surface flow layer

u = mean fall velocity of suspended solids (ss)

k = velocity factor for decomposition by biological oxidation

K_x = diffusion coefficient in the horizontal direction

K_z = diffusion coefficient in the vertical direction

The coordinates are shown in Figure 1. The term for the y -axis is neglected in Equation (1) for ease of calculation.

Since it is very difficult to get an exact solution to Equation (1), the last term is neglected and the following equation is solved:

$$\frac{\partial c}{\partial t} + v \frac{\partial c}{\partial x} + u \frac{\partial c}{\partial z} = K_x \frac{\partial^2 c}{\partial x^2} + K_z \frac{\partial^2 c}{\partial z^2} \quad (2)$$

As the solution of Equation (2), the following separate function is taken:

$$c = T(t)S(x,z) \quad (3)$$

From Equation (2) and (3) we get:

$$\frac{T'}{T} = \frac{K_x \frac{\partial^2 S}{\partial x^2} + K_z \frac{\partial^2 S}{\partial z^2} - v \frac{\partial S}{\partial x} - u \frac{\partial S}{\partial z}}{S} \quad (4)$$

Then by putting both sides of Equation (4) equal to $-n^2$, the following equations are obtained:

$$T' + n^2 T = 0 \quad (5)$$

$$K_x \frac{\partial^2 S}{\partial x^2} + K_z \frac{\partial^2 S}{\partial z^2} - v \frac{\partial S}{\partial x} + u \frac{\partial S}{\partial z} + n^2 S = 0 \quad (6)$$

From Equation (5):

$$T = C_1 e^{-n^2 t} \quad (7)$$

is derived.

In order to solve Equation (6) we transform the coordinates as follows:

$$\begin{aligned} \Phi(\xi, \zeta) &= S(x, z) e^{-\left(\frac{v}{2K_x} x + \frac{u}{2K_z} z\right)} \\ \xi &= \frac{1}{2} \sqrt{\frac{v^2/K_x + u^2/K_z}{K_x}} \cdot x \\ \zeta &= \frac{1}{2} \sqrt{\frac{v^2/K_x + u^2/K_z}{K_x}} \cdot z \end{aligned} \quad (8)$$

The transformation reduces to the following equation, although the calculation is omitted here.

$$\frac{\partial^2 \Phi}{\partial \xi^2} + \frac{\partial^2 \Phi}{\partial \zeta^2} - \left(1 - \frac{4n^2}{v^2/K_x + u^2/K_z}\right) \Phi = 0 \quad (9)$$

By putting

$$m = 1 - \frac{4n^2}{v^2/K_x + u^2/K_z} \quad (10)$$

Equation (9) is rewritten in the following form

$$\frac{\partial^2 \Phi}{\partial \xi^2} + \frac{\partial^2 \Phi}{\partial \zeta^2} - m\Phi = 0 \quad (11)$$

The factor m in Equation (11) denotes the turbulence of lake flow and varies between $0 \sim 1$. In the case of steady flow $m = 1$ and $n = 0$. The smaller the value of m , the greater the turbulence becomes.

We know the values of m for lakes which are subject to a changing annual load of pollutant input. The following example indicates that the value of m is nearly equal to 1. By putting the following data: $v = 100$ m/h, $u = 0.018$ m/h, $K_x = 72$ m²/h, $K_z = 0.36$ m²/h and $n = 0.01$ h⁻¹ into Equation (10), we get

$$m = 1 - \frac{4n^2}{v^2/K_x + u^2/K_z}$$

$$= 1 - \frac{4 \times 0.01^2}{100^2/72 + 0.018^2/0.36} = 0.999992$$

Consequently we may regard any lake flow as a steady one. Then Equation (11) becomes (for a lake flow):

$$\frac{\partial^2 \Phi}{\partial \xi^2} + \frac{\partial^2 \Phi}{\partial \zeta^2} - \Phi = 0 \quad (12)$$

The general solution of Equation (12) is

$$\Phi = (A \cos \lambda \xi + B \sin \lambda \xi) \left\{ C \cosh \sqrt{\lambda^2 + 1} \xi + D \sinh \sqrt{\lambda^2 + 1} \xi \right\} \quad (13)$$

where arbitrary constants A , B , C and D are determined by four boundary conditions. The boundary conditions are set as follows:

$$\begin{aligned} \text{i) } x = 0; c_0 &= \frac{1}{H_1} \int_0^{H_1} c(0, z) dz & \xi = 0; c_0 &= \frac{1}{h_1} \int_0^{H_1} \Phi(0, \xi) e^{b\xi} d\xi \\ \text{ii) } x = L; \frac{\partial c}{\partial x} &= 0 & \xi = L; \frac{\partial \Phi}{\partial \xi} + a\Phi &= 0 \\ \text{iii) } z = 0; uc - K_z \frac{\partial c}{\partial z} &= 0 & \zeta = 0; \frac{M D}{\partial z} - b\Phi &= 0 \\ \text{iv) } z = H_1; \frac{\partial c}{\partial z} &= 0 & \zeta = h_1; \frac{\partial \Phi}{\partial z} + b\Phi &= 0 \end{aligned} \quad (14)$$

where a , b , h and ℓ are all non-dimensional symbols represented by the following equations:

$$\begin{aligned} a &= \frac{v}{K_x} \sqrt{\frac{K_x}{v^2/K_x + u^2/K_z}} \\ b &= \frac{u}{K_z} \sqrt{\frac{K_z}{v^2/K_x + u^2/K_z}} \\ h_1 &= \frac{H_1}{2} \sqrt{\frac{v^2/K_x + u^2/K_z}{K_z}} \\ P &= \frac{L}{2} \sqrt{\frac{v^2/K_x + u^2/K_z}{K_z}} \end{aligned} \quad (15)$$

The solution of Equation (12) can be obtained by determining the eigenvalue λ_n , and eigenfunction ϕ_n , although the mathematical operation is not described here in detail. The eigenvalues λ_n are obtained as roots of the following equation.

$$\tan \lambda_n h_1 = \frac{2b \lambda_n}{\lambda_n^2 - b^2} \quad (16)$$

Finally, the concentration of suspended solids in lake water is represented as follows:

$$c = 4c_0 \sum_{n=1}^{\infty} \frac{e^{-b h_1} b h_1 \lambda_n^2 n (\lambda_n \cos \lambda_n \zeta + b \sin \lambda_n \zeta) \{ \sqrt{\lambda_n^2 + 1} \cosh \sqrt{\lambda_n^2 + 1} (\ell - \zeta) + a \sinh \sqrt{\lambda_n^2 + 1} (\ell - \zeta) e^{a \zeta + b \zeta} \}}{\sin \lambda_n h_1 (\lambda_n^2 + b^2) \{ (\lambda_n^2 + b^2) h_1 + 2b \} \{ \sqrt{\lambda_n^2 + 1} \cosh \sqrt{\lambda_n^2 + 1} + a \sinh \sqrt{\lambda_n^2 + 1} \}} \quad (17)$$

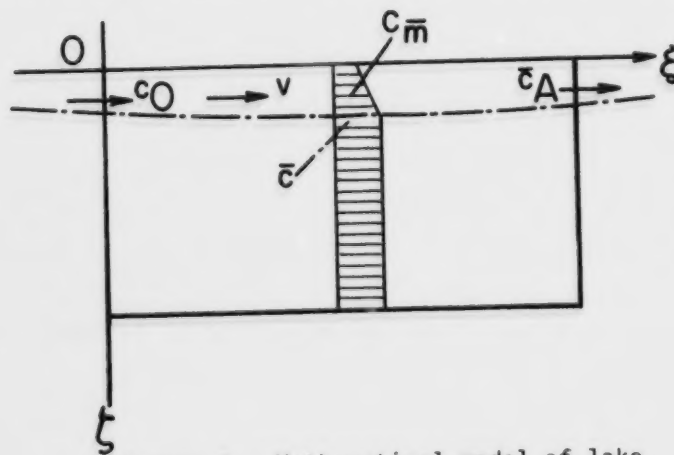


Figure 1. Mathematical model of lake

The mean concentration of the supernatant flow layer (Figure 1) is calculated as follows:

$$c_m = \frac{1}{h_1} \int_0^h c d\xi d\zeta$$

$$= 4c_0 \sum_{n=1}^{\infty} \frac{b\lambda^2 n \left\{ -4a\sqrt{\lambda^2 n + 1} e^{a\xi - \sqrt{\lambda^2 n + 1} \xi} + 2a\sqrt{\lambda^2 n + 1} + (\lambda^2 n + 1 + a^2) \right\}}{\xi(\lambda^2 n + 1 - a^2)(\lambda^2 n + b^2) \{ (\lambda^2 n + b^2)h_1 + 2b \} (\sqrt{\lambda^2 n + 1} + a)} \quad (18)$$

By putting

$$\phi_m = 4 \sum_{n=1}^{\infty} \frac{b\lambda^2 n \left\{ -4a\sqrt{\lambda^2 n + 1} e^{a\xi - \sqrt{\lambda^2 n + 1} \xi} + 2a\sqrt{\lambda^2 n + 1} + (\lambda^2 n + 1 + a^2) \right\}}{\xi(\lambda^2 n + 1 - a^2)(\lambda^2 n + b^2) \{ (\lambda^2 n + b^2)h_1 + 2b \} (\sqrt{\lambda^2 n + 1} + a)} \quad (19)$$

Equation (20) becomes

$$c_m = c_0 \phi_m \quad (20)$$

Next, the mean concentration of suspended solids (Figure 1) at the bottom border line of the surface layer is represented as

$$\bar{c}(\zeta = h_1) = 2c_0 \sum_{n=1}^{\infty} \frac{h_1 \lambda^2 n \left\{ -4a\sqrt{\lambda^2 n + 1} e^{a\xi - \sqrt{\lambda^2 n + 1} \xi} + 2a\sqrt{\lambda^2 n + 1} + (\lambda^2 n + 1 + a^2) \right\}}{\xi(\lambda^2 n + 1 - a^2) \{ (\lambda^2 n + b^2)h_1 + 2b \} (\sqrt{\lambda^2 n + 1} + a)} \quad (21)$$

Similarly, by putting

$$\phi_c = 2 \sum_{n=1}^{\infty} \frac{h_1 \lambda^2 n \left\{ -4a\sqrt{\lambda^2 n + 1} e^{a\xi - \sqrt{\lambda^2 n + 1} \xi} + 2a\sqrt{\lambda^2 n + 1} + (\lambda^2 n + 1 + a^2) \right\}}{\xi(\lambda^2 n + 1 - a^2) \{ (\lambda^2 n + b^2)h_1 + 2b \} (\sqrt{\lambda^2 n + 1} + a)} \quad (22)$$

we get

$$\bar{c} = c_0 \phi_c \quad (23)$$

The factor $\phi_c = \frac{\bar{c}}{c_0}$ denotes the mean concentration of SS in the entire lake.

The mean concentration of runoff may be calculated as follows:

$$\begin{aligned}\bar{c}_A &= \frac{1}{h_1} \int_0^{h_1} c_a d\zeta \\ &= 8c_0 \sum \frac{b\lambda^2 n \sqrt{\lambda^2 n + 1} e^{a\ell - \sqrt{\lambda^2 n + 1} \ell}}{(\lambda^2 n + b^2) \{(\lambda^2 n) h_1 + 2b\} (\sqrt{\lambda^2 n + 1} + a)}\end{aligned}\quad (24)$$

Similarly, putting

$$\phi_a = 8 \sum_{n=1}^{\infty} \frac{b\lambda^2 n \sqrt{\lambda^2 n + 1} e^{a\ell - \sqrt{\lambda^2 n + 1} \ell}}{(\lambda^2 n + b^2) \{(\lambda^2 n + b^2) h_1 + 2b\} (\sqrt{\lambda^2 n + 1} + a)}\quad (25)$$

gives the following equation

$$\bar{c}_A = c_0 \phi_A\quad (26)$$

Finally the equation of concentration at the bottom layer becomes

$$u \frac{\partial c}{\partial z} = 0$$

because $v = Kx = Kz = 0$ at the bottom. Therefore, the concentration at the lake bottom is

$$c_B = \bar{c}(h_1)$$

SOLIDS IN LAKE WATER

The solids contained in lake water are divided into two parts, that portion which remains on a No. 5C filter and the other which passes through it. The former is defined as suspended solids (SS), and the latter, dissolved matter. This method is prescribed by JIS K01050. The sum of these is called evaporation residue, because it is the quantity which remains after evaporation.

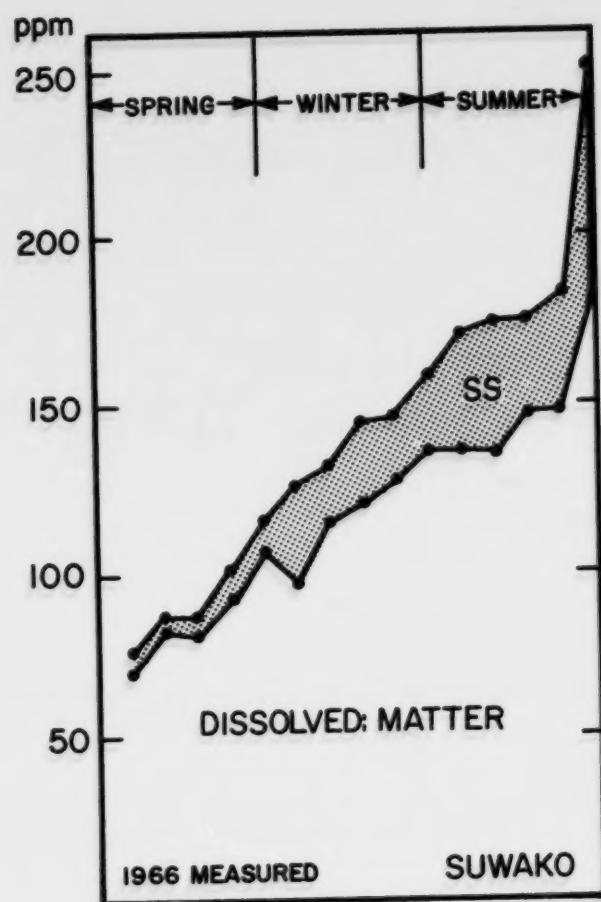


Figure 2. Dissolved matter and SS of Suwako.

The evaporation residue is an unexpectedly large quantity in lakes. Figure 3 shows the results of measurements made in Lake Suwa. Quantities of residue differ according to season. It is thought that the large amount in the summer is due to plankton and the small amount in spring is due to run-off during floods.

As Figure 3 shows, the amount of SS accounts for a small percentage of the residue. Therefore, it would appear that a study of the behavior of suspended particles in lakes would not be of significance.

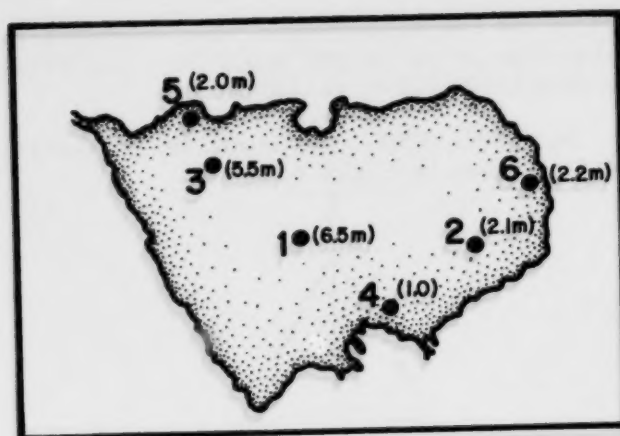
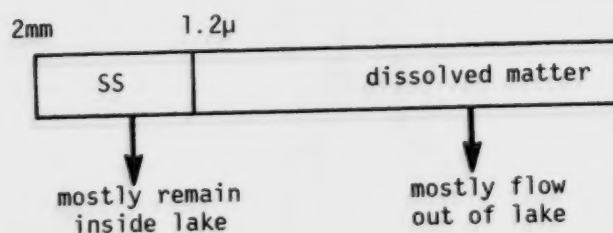


Figure 3. Sampling Sites in Suwako Lake (SS as fraction of total evaporation residue).



However, most of the dissolved matter flows out of the lake, and the major portion of the SS remains inside the lake. Because of this effect the pollution of the lake is dominated by SS. Lake water after filtration with filter cloth, glass filter and micropore-filter becomes transparent. That is, the dissolved matter, which makes up the largest fraction of an evaporation residue, has no influence on the transparency of lake water. Furthermore, organic matter accounts for 70% of the total SS, but the non-organic fraction predominates as dissolved matter. From this it is clear that the properties and behavior of SS have a strong influence on lake pollution.

As mentioned before, evaporation residues increase in the summer. The amount of SS therefore also enlarges. This may be due to plankton blooms.

In winter and spring, when the measurements were performed, a diatom, *Asterionella*, was dominant, and in summer (July) the green waterweed *Microactinium* was generated in large quantities, followed by *Synedra*, *Microcystis*, and finally algal blooms of a blue-green color. These facts indicate that chemical and ecological studies should also be considered in addition to an understanding of the physical behavior of suspended solids in lakes.

SETTLING RATE OF POLLUTANT PARTICLES

In the calculation of the hydrodynamic lake equations it is difficult to evaluate the settling rate of pollutant particles. Empirical measurements of settling in the lake were conducted as follows.

From August to December, 1966, the quantity of settling material was measured by the apparatus shown in Figure 4.

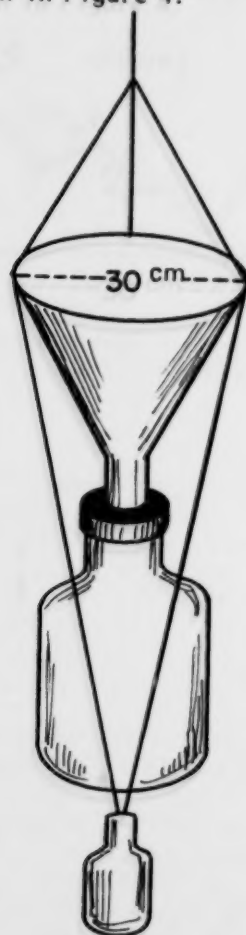


Figure 4. Measuring apparatus.

The measurements were performed for 42 days and at 6 sites in the lake as shown in the map of Figure 3. The mean value of each point is given in Figure 5.

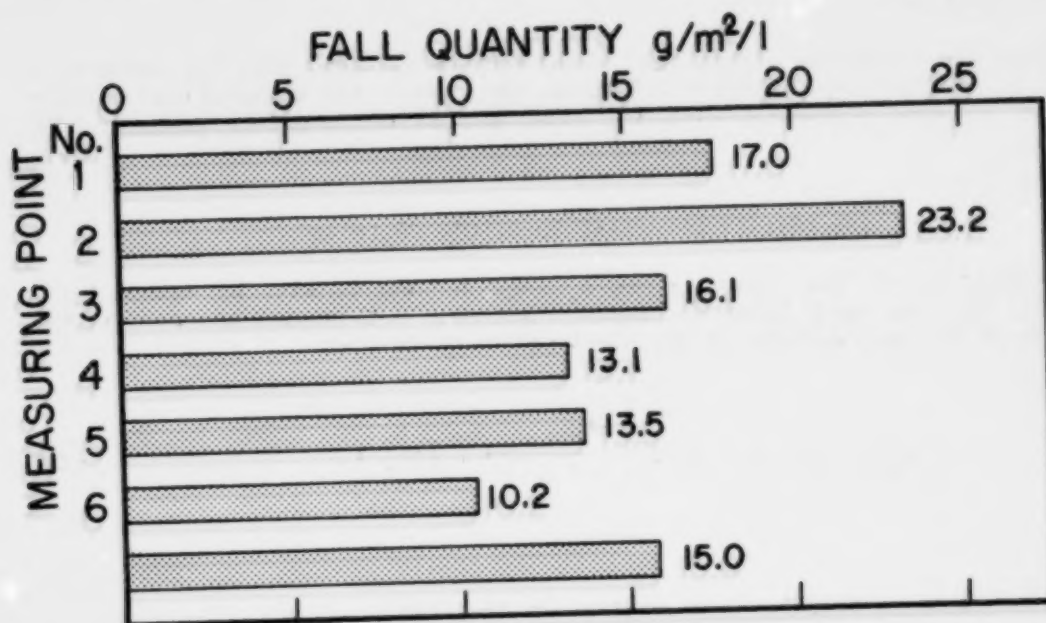


Figure 5. Settling rates.

On windy days the sediment was stirred up and the quantity of material settling was increased. The average wind velocity was 3 m/sec over 42 days.

It is possible to estimate the settling velocity of pollutant particles from the above data. If c denotes the mean concentration of SS in lake water, and u , the settling rate of solid particles, the falling material per unit area and unit time becomes

$$uc = 15.6 \text{ g/m}^2/\text{day} = \frac{15.6 \times 10^{-6}}{2.5 \times 24} + 0.26 \times 10^{-6} \text{ m}^3/\text{m}^2/\text{h}$$

where the unit weight of a particle is taken as 2.5 g/cm^3 . For the concentration $c = 14.5 \times 10^{-6}$, we get

$$u = \frac{0.26 \times 10^{-6}}{14.5 \times 10^{-6}} = 0.018 \text{ m/h} = 0.0005 \text{ cm/sec}$$

This value corresponds to a mean particle diameter of 3.5μ as derived from Stoke's equation.

From the foregoing theoretical equations it is found that the value of u should be in the range $0.0003 \sim 0.0005 \text{ cm/sec}$. Thus, the mathematical estimation is in good agreement with the experimental measurements made in Lake Suwako.

THE ABILITY OF A LAKE TO DILUTE POLLUTANTS

Estimation of the input values K_1 , K_2 , H , and v , etc. by mathematical methods, can save much labor and money. One such method uses the conditional equation of the mass balance of pollutant solids as follows:

$$c_0(1 + \alpha\tau)(1 - \phi_A)Q = \frac{BH_1L}{\tau} \text{ cm} + u \bar{c}(h_1)A \quad (29)$$

where

τ = residence time for surface flow in the lake

a = surface area of lake

Q = quantity of water flowing into lake

Equation (29) is arranged in the following form

$$\frac{uA}{Q} \phi_c = 1 - \phi_A - \phi_m \quad (30)$$

This is used to check whether the inputs are proper or not in the calculations of ϕ_c , ϕ_A and ϕ_m . Since it is generally allowed to set $\phi_c \div \phi_m$, Equation (30) may be rewritten as follows.

$$\phi_c = \frac{1 - \phi_A}{1 + \frac{uA}{Q}} \quad (31)$$

The factor ϕ_c relates to the dilution ability of the lake, since it is the ratio of the mean concentration of lake water to that of the inflow. The smaller the value of ϕ_c , the larger the dilution ability of the lake. Equation (31) shows that the larger the lake area and the smaller the quantity of influx, the smaller the value of ϕ_c becomes. Consequently, the ratio $\frac{uA}{Q}$ is an important index for the estimation of dilution ability. This relationship is examined for the three lakes, Teganuma, Suwako and Kasumigaseki.

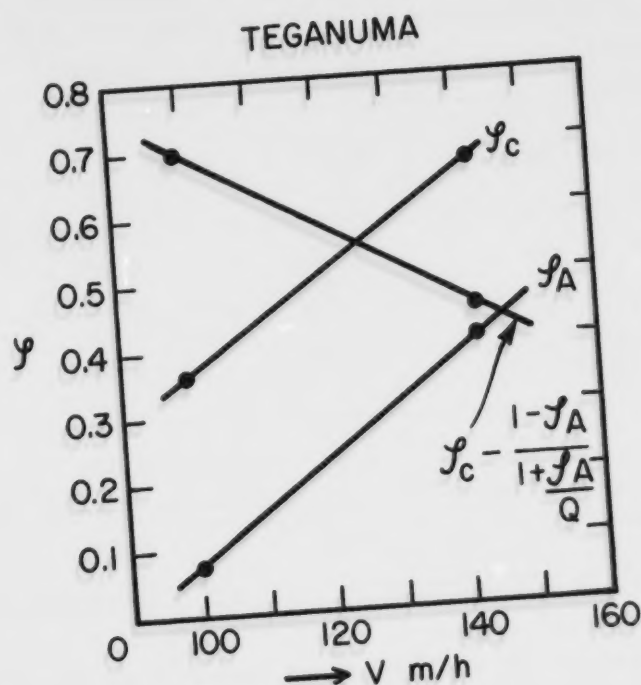


Figure 6. Determination of ϕ_c .

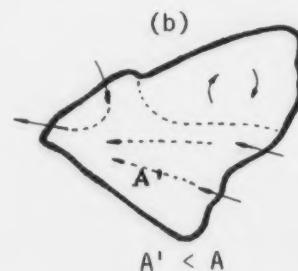
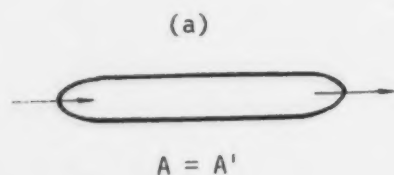
Before discussing the dilution abilities of the three lakes, the method for using the conditional Equation (30) is shown for Lake Teganuma. In Figure 6 the values of ϕ_c and ϕ_A corresponding to two points $v = 100 \text{ m/h}$, and $v = 143 \text{ m/h}$, are plotted and the line of the conditions equation $\phi_c = \frac{1 - \frac{uA}{Q}}{1 + \frac{uA}{Q}}$ is drawn.

The point where the ϕ lines intersect, ($v = 125$ m/h) gives the answer. In this case the velocity v becomes a major variable, because the values of u , K_x and K_z are restricted to small ranges.

TABLE 1. DILUTION ABILITIES OF THREE LAKES

	Teganuma	Suwako	Kasumigaseki
Lake Area, A (m^2)	118,000	13,300,000	171,000,000
Inflow Q (m^3)	6,790	46,800	1,140,000
$\frac{uA}{Q}$, $u = 0.018$ (m/h)	0.31	$\frac{A}{A'} \begin{matrix} 5.11 \\ 3.31 \end{matrix}$	2.7
Lake length, L (m)	7,000	4,000	300,000
Surface layer thickness, H (m)	0.78	0.5	1.0
ϕA	0.27	0.013	0.022
ϕc	0.55	0.229	0.258

When we calculate the value of $\frac{uA}{Q}$ we need to take the effective lake area A' through which the inflowing water passes directly.



In the case of (a) in the drawing A is equal to A' , but in the case of (b) A' should be estimated to be much less than A because of the effect of back currents and eddies. Among the three lakes, Lake Suwako corresponds to the case of (b). The dilution ability of Teganuma is worst with a value of $c = 0.55$. In the other two lakes the concentration of inflowing pollutants is diluted to about one fourth on the average.

CONCENTRATION OF SS AND COD IN LAKE WATER

Among the many indices for representing pollution of lake water, chemical oxygen demand (COD) is a typical one. Figure 7 shows the growth of COD values in 3 lakes, Teganuma, Suwako and Kasumigaseki in which pollution has increased in the last 10 years.

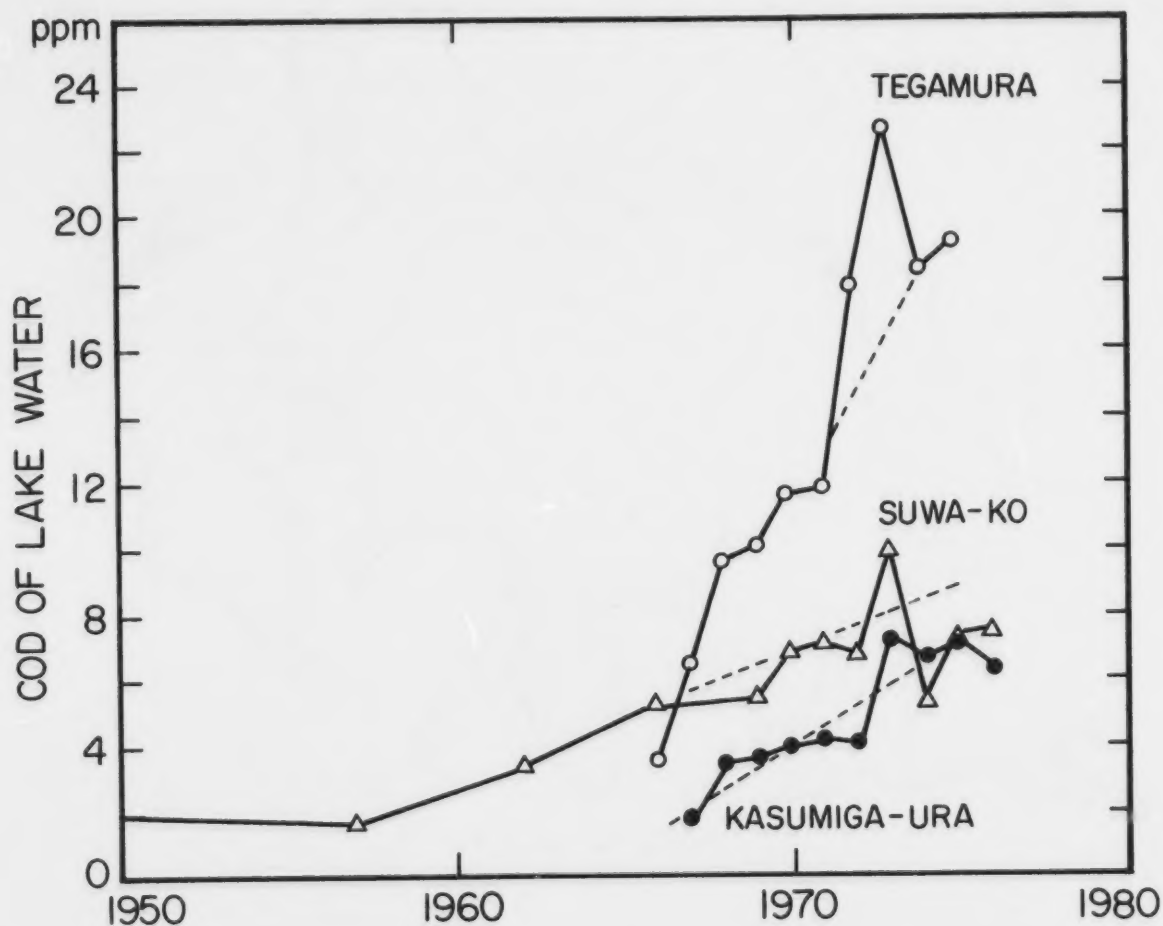


Figure 7. Plot of COD against time in three lakes.

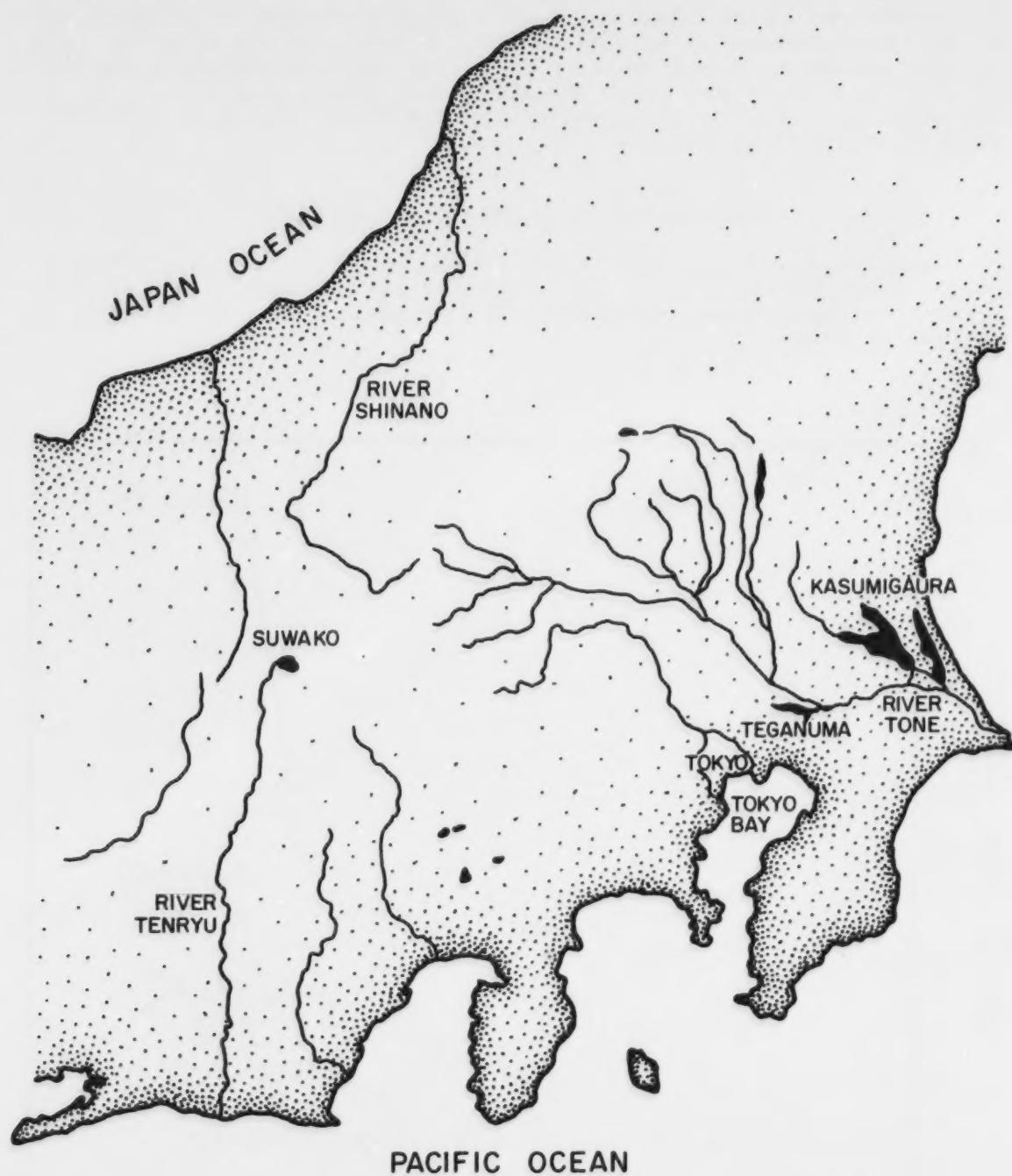


Figure 8. Location of the three lakes.

When the lakes were not polluted as shown in Figure 7, the value of COD amounted to only 2 ppm. But after pollution began, COD increased to 20 ppm in Teganuma, and 7 ppm in Suwako and Kasumigaura.

The relationships between the SS concentration and the COD of lake water are shown in Table 2.

TABLE 2. CONCENTRATION OF SS AND COD OF THREE LAKES

	Teganuma	Suwako (1966)	Kasumigaura (1974)
SS (ppm)	55.1 (mean of 15 values)	14.5 (mean of 42 values)	8.67 (mean of 12 values)
COD (ppm)	16.8 (")	4.95 (mean of 63 values)	6.8 (")
BOD (ppm)	12.6 (")	5.27 (")	2.55 (")
COD/SS	0.30	0.34	0.78

As long as COD (or BOD) represents the organic fraction of suspended solids it appears that there should be some relationship between them. As an approach to this idea the ratio COD/SS is considered. This ratio is nearly equal in Lakes Teganuma and Suwako, but is much higher in Lake Kasumigaura.

Among nutrients, phosphorus is regarded as one of the most important elements for maintaining an ecological and chemical cycle. Table 3 gives the values of total phosphorus concentrations for the three lakes.

TABLE 3. T-P OF THREE LAKES

		Teganuma	Suwako	Kasumigaura
T-P	(mg/l)	0.91	0.05	0.05
SS	(mg/l)	55.1	14.5	8.67
TP/SS		0.016	0.022	0.052

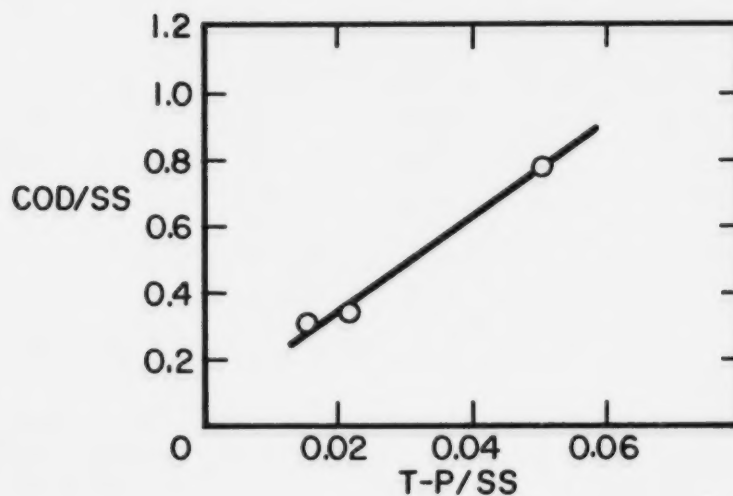


Figure 9. Relationship between COD/SS and T-P/SS.

Figure 9 shows the close relationship between the ratios COD/SS and T-P/SS although the amount of data are insufficient to make a general rule. We can say however, that the large value of COD/SS in Kasumigaura may be related to the high value of T-P/SS. The extraordinarily high values of SS and COD in Teganuma results from the small dilution ability of the lake.

QUANTITIES OF POLLUTANTS DEPOSITED AND COD OF SEDIMENT

The mean concentration of suspended solids at the lake bottom is given as

$$\bar{c}_B = \bar{c}(h_1) = c_o \phi c$$

from Equation (28).

Here we assume that the concentration of inflowing pollutant solids increases in the following expression:

$$c_o = c_{oo} (1 + \alpha t) \quad (32)$$

The quantities of solid pollutants which are deposited on the lake bottom per unit area and per unit time are represented as follows:

$$\begin{aligned} Ws &= \int_0^t u c_B dt \\ &= c_{oo} \phi c u(t + \frac{1}{2} \alpha t^2). \end{aligned} \quad (33)$$

If the quantity Ws is mixed to depth H_2 of the base sediment, the concentration of pollutant solids in the sediment becomes

$$c_S = \frac{Ws}{\frac{H_2}{1 + e_o}} = (1 + e_o) \frac{Ws}{H_2} \quad (34)$$

where e_o denotes the void ratio of the undisturbed base sediment. It is assumed that the unit weight of the pollutant solid is equal to that of the native base soil. The value c_s cannot be measured in practice because it is impossible to distinguish exogenous pollutant solids and native sediments with respect to the soil phase. But if we presume that the pollutant solids have a COD and the native sediment does not, it is possible to distinguish them.

By putting $\omega = \text{COD/SS}$ in lake water, we get

$$\text{COD}_{\text{Sediment}} = (1 + e_o) \frac{Ws}{H_2} \omega \quad (35)$$

This is the calculated COD value of the sediment which can be obtained theoretically. This also can be measured by sampling. In this case, if the accumulated pollutant solids are sampled perfectly so that none are missed at depth, the calculated and measured values should be nearly equal.

If they differ it may be due to:

- 1) incomplete sampling
- 2) anaerobic decomposition
- 3) other

In any case the difference is represented by the ratio

$$\tau = \frac{\text{COD}_S (\text{measured})}{\text{COD}_S (\text{calculated})} \quad (36)$$

Now the numerical example of Lake Teganuma is cited.

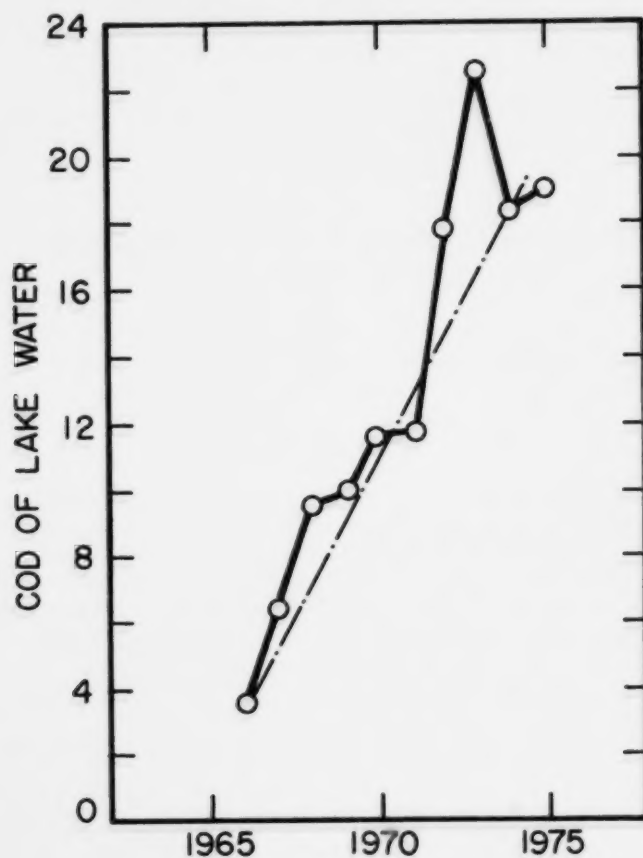


Figure 10. Growth rate of COD of water in Lake Teganuma.

As the figure shows, the value of COD was 3.6 ppm in 1966. After 8 years it increased to 18.5 ppm. Thus,

$$1 + \alpha t = \frac{18.5}{3.6} = 5.139 \quad \text{and therefore}$$

$$\alpha = \frac{5.139-1}{t} = \frac{4.139}{8 \times 8760} = 6 \times 10^{-5} \text{ h}^{-1}$$

So the concentration of influx in the beginning year 1966 becomes

$$c_{00} = \frac{3.6}{w} = \frac{3.6}{0.3} = 12 \text{ ppm}$$

$$\begin{aligned} \sum W_S &= c_{00} \phi c u(t + \frac{1}{2} \alpha t^2) \\ &= 12 \times 10^{-6} \times 0.55 \times 0.018 (7.080 + \frac{1}{2} \times 6 \times 10^{-5} \times 70,080^2) \\ &= 0.0258 \text{ m}^3/\text{m}^2 \end{aligned}$$

$$\begin{aligned} \text{COD}_S &= (1 + e_0) \frac{W_S}{H_2} w \\ &= (1 + 4) \times \frac{0.0258}{0.5} \times 0.3 \\ &= 0.0775 = 77.5 \text{ mg/g} \end{aligned}$$

$$\text{CODs(measured)} = 44.6 \text{ mg/g (average of 24 values, May, 1975)}$$

$$\tau = \frac{44.6}{77.5} = 0.57$$

The difference between the calculated and measured values is large. In this case, sediment samples were taken from depths less than 0.5 m. This suggests that 0.5 m is not deep enough to sample the entire accumulation of pollutant solids. If we calculate the deposit quantity with $H_2 = 0.9$ m, we get the value $\text{COD}_S = 43.0$ mg/g, which is nearly equal to the measured one. This indicates that the sampling should have been conducted to a depth of 0.9 m.

Table 4 shows the results of similar calculations for the other pollution indices using the above correction.

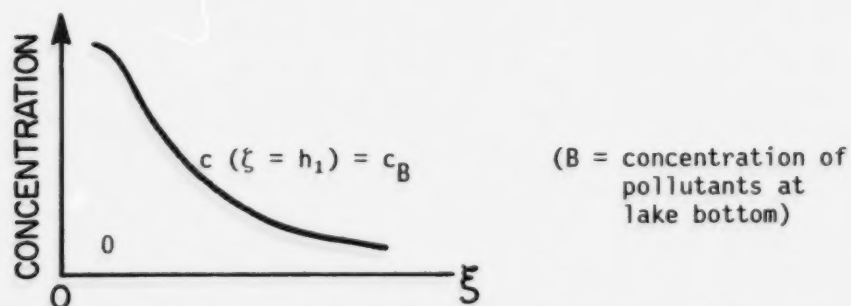
TABLE 4. RATIOS OF τ FOR OTHER POLLUTION MEASURES

Water		Sediment (calculated) mg/g	Sediment (measured) mg/g	
BOD	0.2/SS	28.7	7.9	0.27
T-N	0.1/SS	14.3	4.75	0.33
T-P	0.016/SS	2.29	1.99	0.87

From this table it is conjectured that the phosphorus compounds in the sediment underwent some anaerobic decomposition. For BOD and Total Nitrogen the circumstances are quite different. Presumably most of the organic materials associated with BOD and T-N were decomposed after deposition at the lake bottom.

DISTRIBUTION OF CONTAMINANTS IN LAKES

In the previous sections the paper describes only the organic pollution of lakes. But some lakes are also contaminated by toxic heavy metals. Lake Teganuma is a good example of this situation. Here the distribution of contaminant deposits in the lake is accounted for by using the previously discussed theoretical equation



In order to calculate the quantities of contaminants deposited, it is necessary to know the concentration of SS at the lake bottom. This is derived from Equation (37) as follows:

$$c(\xi = h_1) = 2c_0 \sum_{n=1}^{\infty} \frac{h_1 \lambda^2 n}{(\lambda^2 n + b^2) h_1 + 2b} e^{(a - \sqrt{\lambda^2 n + 1}) \cdot \xi} \quad (37)$$

Since the quantities of solids deposited per unit area and unit time are $uc(h_1)$, the contaminants contained in them should be distributed according to the function:

$$e^{(a - \sqrt{\lambda^2 n + 1}) \cdot \xi}$$

The Teganuma marsh is cited as an example, where the measurement of heavy metals in sediment was conducted at the 6 sites shown in Figure 11.

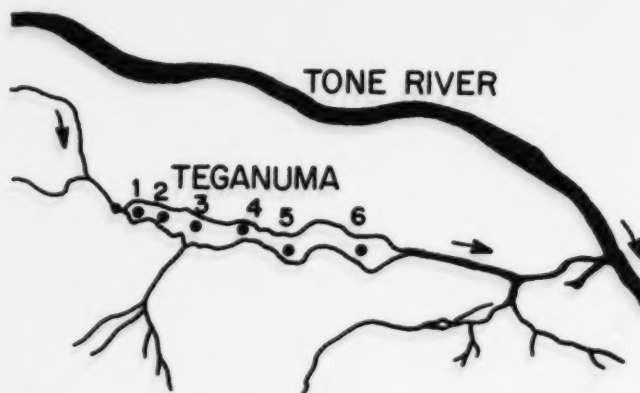


Figure 11. Sampling sites in Teganuma marsh.

The heavy metals measured were: Cd, Zn, Cu, Pb, Cr, Ni, Mn, Fe. The samples were taken from the surface to a depth 50 cm of sediment and divided into 5 equal layers. The concentrations of Zn and Cu at the six sites are given in Table 5.

TABLE 5. DISTRIBUTIONS OF Zn AND Cu IN TEGANUMA MARSH
(ppm and %)

	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
Zn	378(100)	61.7(16.3)	56.4(14.9)	43.3(11.5)	54.1(14.3)	53.0(14.0)
Cu	147(100)	27.0(18.4)	35.7(24.2)	23.5(16.0)	37.2(25.3)	36.5(24.8)

The figures of Table 5 are plotted in Figure 12.

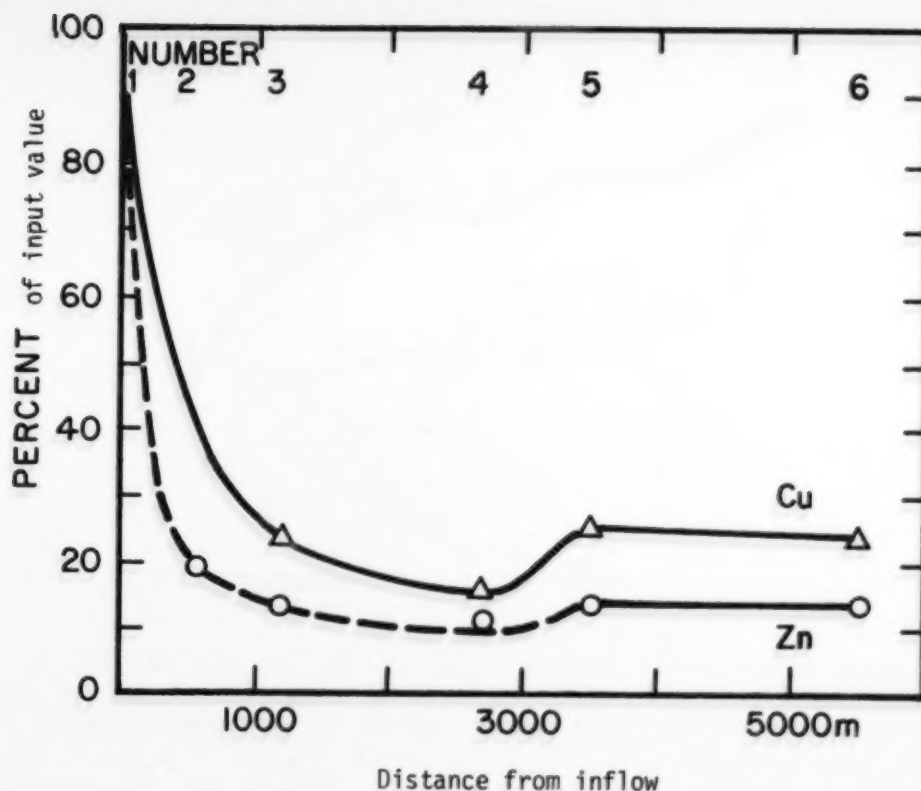


Figure 12. Distributions of Zn and Cu in Teganuma Marsh.

Figure 12 shows that the distribution curves of both metals strongly decline because of their heavy specific weights. These curves appear quite reasonable and within theoretical expectations except for the small deviations at site No. 5 which result from the neck at the lake center.

It is worthwhile to note that the theoretical curves obtained by the following inputs:

and

Cu	$u = 0.11 \text{ m/h}$	(common $v = 125 \text{ m/h}_1$, $Kx = 72 \text{ m}^2/\text{h}$, $Kz = 0.36 \text{ m}^2/\text{h}$, $L = 7000 \text{ m}$)
Zn	$u = 0.14 \text{ m/h}$,	

are in good agreement with the measured ones. This is evidence that most of the Zn and Cu was transported to the lake by inflowing rivers.

The same relationships are noted for Fe and Mn and for Zn and Cu (Figure 13), with a slight difference.

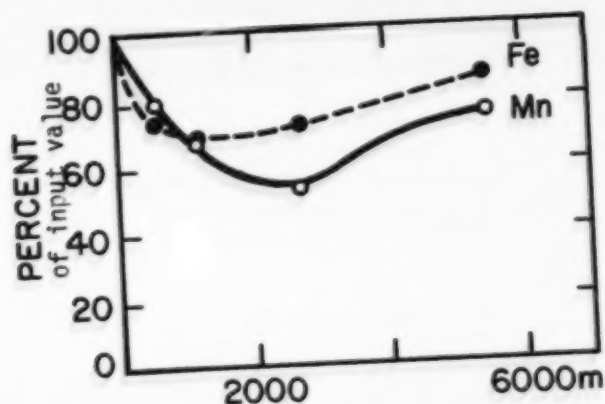


Figure 13. Distributions of Fe and Mn.

There is no great change in concentrations along the length of the lake. Therefore, these flat curves do not represent the precipitation of metals, but may perhaps be deviations from the normal characteristics of native sediment soils.

CONCLUSION

To understand pollution of lakes by solid materials it was necessary to understand the hydrodynamic behavior of the solid pollutants. To achieve this end theoretical equations were deduced. The first result derived from these equations was the concept of the dilution ability of a lake. This was illustrated with examples of three lakes. Next, the theoretical estimation of the deposited quantities of solid pollutants was described, and the relationships between the accumulated quantities of pollutants and common pollution indices for sediment was discussed. Finally, the hydrodynamic equations were applied to the distribution of toxic heavy metals in lake sediments. From the above results it may be concluded that hydrodynamic analysis of lake pollution is a useful tool.

RESEARCH ASPECTS

The law generally provides that research may be performed in any area necessary to support the purposes of the Act. It specifically describes health effects research but it states that epidemiological research, which normally has been the responsibility of the OSHA (the Office of Safety and Health Administration) shall also be a responsibility of EPA: Testing in this respect is biological, either for effects on human health (directly from environmental experience or occupational experience); or through toxicological tests using rats, mice, and other experimental animals.

The new priorities in research that were not handled by EPA before include the authority to control and thus investigate manufacturing processes. We may determine that a chemical which currently is being manufactured in open production can be produced only in closed systems. We may say that the particular kind of piping that's being used in production may not be used, but rather another kind of pipe must be used. We may say that the chemical may be produced for only a short period of time and then there must be time to clean the machinery. The law is quite broad in terms of its capability of looking at manufacturing processes.

In terms of testing for health effects, the authority extends to providing that industry do all of the testing, and industry must test for all effects that EPA requires. The testing procedures, however, have one important control--that control being that the EPA Administrator must find that there is a reason to test, and this finding may be challenged in court. The Administrator must decide what testing will be performed. When the test results are delivered, he may not continue to ask for additional tests. He must know what he wants when he asks for testing the first time.

A new type of research, at least of increased importance, is what one might call discovery monitoring. Instead of attempting to emphasize quality assurance and accuracy of data, the law says that the EPA should be interested primarily in the presence of the chemical in the environment; and, that generally all contact with chemicals in the environment should be reduced. Therefore emphasis in research needs to be in the direction of being able to detect substances which were not detected before; the development of new methods, the extension of capabilities for analyses into new areas and the ability to detect chemicals that were not previously recognized as problems.

Epidemiology, I've mentioned, is a new area of emphasis. Formerly the responsibility of OSHA, epidemiology research is expressly described as being important under the Toxic Substances Act. To provide coordination, the Act says that the EPA, if it plans to engage in epidemiological research, needs to coordinate that activity with NIOSH, the National Institute of Occupational Safety and Health, the research arm of the Department of Labor in this area.

Another area that becomes more important in EPA is the area of terrestrial ecology. EPA has had several laboratories, including the Corvallis laboratory, the one at Gulf Breeze, the one in Narragansett, and the one in Duluth, that are concerned with aquatic ecotoxicology. The Act says that we must protect the terrestrial environment with equal vigor as with the aquatic

THE TOXIC SUBSTANCES CONTROL ACT (TSCA):
HOW IT AFFECTS EPA FROM A RESEARCH
AND ENFORCEMENT STANDPOINT

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INTRODUCTION

The Office of Toxic Substances is relatively new and Mr. Steven Jellinek was only recently confirmed as an Assistant Administrator of EPA to head the Office. The purpose of the Office is to administer a law, the Toxic Substances Control Act, which was passed in October of 1976 and became effective January 1, 1977.

The purpose of the law is primarily to gather health effects data and to make these data available to everyone--to citizens of the United States, to other countries, to any labor union member or to anyone who wishes to have the information. A second purpose of the Act is to gather new health effects information through the testing of toxic chemicals. Really, the name, "Toxic Chemicals" is not quite correct. The law should be titled "The Regulation of Industrial Chemicals". It is not restricted to toxic chemicals but is expected to be involved with any existing or new industrial chemical. A third objective is to control the chemical industry in the prevention of pollution.

Some people have said that this Act is to fill the gaps in existing EPA legislation. It supplements the capability to deal with water pollution and it increases the capability to deal with air pollution. It's concerned with waste disposal, with products and product labeling, and with all aspects of the chemical production industry. The fourth, and last major function of the law, is to screen chemicals for hazard before they are produced commercially. Every new chemical must be subjected to analysis by EPA. EPA might determine that the chemical may be manufactured, might decide that it should not be manufactured or may place any one of many different kinds of restrictions on production of the chemical. These restrictions might be in the location of production facilities, in the quantity of production, in the use, in the method of production, or any limitation that would appear to make the chemical safer--either safer for the worker, or safer for citizens.

RESEARCH ASPECTS

The law generally provides that research may be performed in any area necessary to support the purposes of the Act. It specifically describes health effects research but it states that epidemiological research, which normally has been the responsibility of the OSHA (the Office of Safety and Health Administration) shall also be a responsibility of EPA: Testing in this respect is biological, either for effects on human health (directly from environmental experience or occupational experience); or through toxicological tests using rats, mice, and other experimental animals.

The new priorities in research that were not handled by EPA before include the authority to control and thus investigate manufacturing processes. We may determine that a chemical which currently is being manufactured in open production can be produced only in closed systems. We may say that the particular kind of piping that's being used in production may not be used, but rather another kind of pipe must be used. We may say that the chemical may be produced for only a short period of time and then there must be time to clean the machinery. The law is quite broad in terms of its capability of looking at manufacturing processes.

In terms of testing for health effects, the authority extends to providing that industry do all of the testing, and industry must test for all effects that EPA requires. The testing procedures, however, have one important control--that control being that the EPA Administrator must find that there is a reason to test, and this finding may be challenged in court. The Administrator must decide what testing will be performed. When the test results are delivered, he may not continue to ask for additional tests. He must know what he wants when he asks for testing the first time.

A new type of research, at least of increased importance, is what one might call discovery monitoring. Instead of attempting to emphasize quality assurance and accuracy of data, the law says that the EPA should be interested primarily in the presence of the chemical in the environment; and, that generally all contact with chemicals in the environment should be reduced. Therefore emphasis in research needs to be in the direction of being able to detect substances which were not detected before; the development of new methods, the extension of capabilities for analyses into new areas and the ability to detect chemicals that were not previously recognized as problems.

Epidemiology, I've mentioned, is a new area of emphasis. Formerly the responsibility of OSHA, epidemiology research is expressly described as being important under the Toxic Substances Act. To provide coordination, the Act says that the EPA, if it plans to engage in epidemiological research, needs to coordinate that activity with NIOSH, the National Institute of Occupational Safety and Health, the research arm of the Department of Labor in this area.

Another area that becomes more important in EPA is the area of terrestrial ecology. EPA has had several laboratories, including the Corvallis laboratory, the one at Gulf Breeze, the one in Narragansett, and the one in Duluth, that are concerned with aquatic ecotoxicology. The Act says that we must protect the terrestrial environment with equal vigor as with the aquatic

environment. Thus, the Agency will have to increase its activities in terrestrial ecology.

The last new area of research is in the area of exposure. The objective of the Act could only be met by reducing exposure to all chemicals. The information gathered from the previous studies and from existing studies is to be combined so that interpretations can be made with regard to exposure. In the evaluation of chemicals, the assessment of chemical hazard becomes very important. It is expected that the EPA will follow the procedure of collecting chemical dossiers, that is documentation of the various kinds of effects; and that in many cases, industry will be required to prepare these dossiers. Testing will be done to complete the dossiers and in general, they will contain packages that include physical/chemical data. These data will include production and trends, procedures for manufacturing the chemical, use and consumption processes, health information, chemical fate and transport information, environmental effects, and exposure. These data must be collected, not only by a chemical manufacturer who produces the chemical in the United States, but also by importers who bring chemicals into the country. The importers must, therefore, either obtain the data directly from foreign companies or they must arrange to have the foreign company submit the data itself. We've been told that probably the foreign manufacturer would prefer to present the data directly to the EPA rather than presenting that data to the importer, who on receipt of production data might be tempted to sell the information on the manufacturing procedures to someone in the United States. For the purposes of protection of confidentiality they, the manufacturers, may submit the data directly to the Office.

There are some problems that must be faced in the testing of chemicals. For example, the problem of cost-sharing. In the United States if the EPA were to require a complete battery of tests, those tests might cost half a million dollars. If a company in the United States were required to spend that money on a chemical and the data were made available, this might affect the value of a chemical to be imported from another country. Therefore, we're very much concerned with this type of requirement and the ways in which cost-sharing may be made effective. In the United States cost-sharing must take place between the companies that are involved in U. S. production. If the companies themselves do not reach agreement, the EPA Administrator is required to bring about agreement or to impose a cost sharing solution.

The information under the Toxic Substances Act may be of interest to OSHA, the Food and Drug Administration, the Department of Transportation, the Department of Interior, or an other agency which has to do with chemical manufacture. The Act contains considerable information on the ways in which information shall be shared within the U. S. government and with foreign governments. If the United States produces a chemical and then regulates that chemical's production, not only are we responsible for notifying U. S. Agencies, but also any importing country must be notified of the hazard of the chemical that it is receiving. As is usual practice, the United States may ban production within the United States, for sale within the United States, and still permit production for sale overseas. In cases of this kind, a formal notification of the toxicity of the chemical and the status of regulation must be sent to the foreign government.

In all of the regulations that are written under the Toxic Substances Act, economics must be taken into account. We must take into consideration, in writing the regulation, the cost of the testing being required, any potential delay in production of the chemical, and other economic factors. No undue or unnecessary hardship may be imposed on the prospective manufacturer. There is a provision in the law which permits economic issues to go to litigation; that is, manufacturers may appeal EPA's ruling, based on economics.

ENFORCEMENT

Enforcement of the Act is primarily through the Regional offices of EPA. The EPA's ten regions have substantial authority for inspection and for assuring that all of the data are presented to EPA. Inspection may be carried out within the normal court procedures but it may also be carried out unexpectedly by entering a plant without a warrant. The Act provides for access to company records and inspection of production facilities without warning. Violations under the Act are severely penalized. Any person who knowingly fails to produce information or fails to make that information available on a required time scale is subject to \$25,000 a day criminal penalty and \$25,000 a day civil penalty.

This Act is primarily concerned with individual chemicals and categories of chemicals. The Japanese Toxic Substance Law deals specifically with PCBs (polychlorinated biphenyls). Our law also deals specifically with PCBs. We are required to have labeling and disposal regulations by the end of 1977; and by the end of 1978, PCBs are banned completely from production and new use. We will still have the same problem that everyone has in dealing with PCBs currently in transformers and in determining how they should eventually be disposed. There remains the problem of refills of transformer fluids when required and there is no longer any PCB production. However, the law clearly requires that PCBs no longer be produced for sale.

The Toxic Substances Control Act will also be used to regulate chlorofluorocarbons. We are banning aerosol use of chlorofluorocarbons in December of 1977 and we're considering the non-aerosol use for possible regulation in the future. A regulation is being developed for polybrominated biphenyls (PBB) as a result of the accident with PBBs in Michigan and the exposure and loss of agricultural products and their impact on human health. American companies were thought not to be producing PBBs, but it was discovered that PBBs are produced in the United States for sale overseas. One of the decisions we must make is whether to continue to produce PBBs for export or to ban them completely.

INTERNATIONAL IMPLICATIONS

Perhaps the most important regulation for Japanese industry, as well as the U. S. industry, is the regulation requiring an inventory of chemicals. We've had the benefit of the Japanese experience with a list of chemicals. We are preparing our own list. We think that our list will be substantially larger than the 20,000 chemicals produced on the list by METE. The list we

expect to have will include at least 34,000 chemicals, but it may be much larger. We anticipate that there will be approximately 1,000 new chemicals per year to add to the list of existing chemicals. Rather than follow the general practice of the European countries of the OECD or the practice in Japan of dealing with only the new chemicals, we expect to deal more with old chemicals than the new ones. We think this approach is valid from the standpoint that there is a greater volume of old chemicals which have wider and more general use than the newly developed ones. Because of the large volume of old chemicals and the expected steady addition of new ones, we are interested in the development of common testing practices.

In negotiations with OECD and with the Common Market and in bilateral meetings with Japan and other countries, we are considering that we should be able to reach full agreement in the near future on the initial physical and chemical tests that should be performed. Through OECD we have established a series of testing work groups. These testing work groups will be meeting in the lead countries, and in February of 1978 in the United States, to consider at least five major categories of tests. There will be a working group that is concerned with chemical/physical data; a work group concerned with persistence testing; another work group with ecotoxicology (ecosystem ecology testing); a fourth group which would be concerned with short term tests (eye tests, acute exposure tests, and subchronic toxicity tests); and a final group would be concerned with long term toxicity testing. The procedures developed must be sufficiently common to harmonize the regulation of the chemicals in such a way that we would not be presenting non-tariff trade barriers. We want to use the Act in such a way that we do not decrease the possibility of international trade in chemicals.

In international activities we are particularly concerned with the capability to share epidemiological experiences. We think that we should learn from the Japanese spills of mercury and cadmium and the information that you've gained from those spills. We would like to have a rather complete study of the water below the now closed Azo dye factories in the Osaka area. We would like to see a system where full information is obtained and shared about the U. S. spills, such as the accidental release of dioxin in Kansas City and of polybrominated biphenyls in Michigan. In other words, we would like to be able to gain information from any industrial accident or related exposure to chemicals. We believe that it would be most effective internationally to share toxicological testing capabilities. There's a shortage of toxicologists and we believe sharing the capability internationally will be of mutual benefit. We would like to use similar hazard assessment procedures such that a chemical dossier prepared in Japan would be similar to a chemical dossier prepared in the Common Market countries or in the United States.

We find much to admire in the administration of the Japanese Law. We are impressed by your ability to look at chemicals and declare certain ones safe for production. We have been told that of the chemicals considered, approximately 189 have been declared safe and 19 are considered to require chronic toxicity testing. Your development of programs for the use of biodegradation tests and bioaccumulation tests are looked on with great interest. The procedures that you follow in testing chemicals through a series of steps are the type we would like to follow. We think the cooperation that could be

developed and has been developed in this committee and in other committees is very important. We value greatly such cooperation and we look forward to productive and useful exchange of information, both here and in subsequent sessions.

MITIGATION FEASIBILITY FOR THE KEPONE-CONTAMINATED
JAMES RIVER, VIRGINIA

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ABSTRACT

As the result of carelessness in production and in waste disposal the health of Kepone production workers at Hopewell, Virginia, has been jeopardized and a 70-mile reach of the James River has been contaminated by this hazardous and persistent pesticide. In addition, Chesapeake Bay is threatened. EPA's Kepone Mitigation Feasibility Project was undertaken to address the threat posed by Kepone contamination and to recommend possible cleanup action. Responsibility for the project was assigned to the Criteria and Standards Division, Office of Water Planning and Standards, in EPA, with support from an Energy Research and Development Agency laboratory (the Battelle Pacific Northwest Laboratories), the U. S. Army Corps of Engineers, EPA's Gulf Breeze Environmental Research Laboratory and the Virginia Institute of Marine Science. The project involves: (1) assessment of the biological and ecological impact of Kepone through literature search, laboratory and field studies; (2) assessment of the potential sources of continuing contamination by inflows into the James River; (3) sampling and evaluation of the contamination in the James River; (4) modeling the movement of contaminants; and (5) evaluation of potential conventional and nonconventional methods for mitigating the problem. Preliminary results indicate that continuing inflows of contamination into the James River exist, and that there is no evidence of any degradation in the pesticide or indication that natural causes will substantially alleviate the problem in the foreseeable future. While some mitigation methods now look promising, their cost-effectiveness must be evaluated. A full report of EPA's Kepone Mitigation Feasibility Project and recommendations for alleviating the Kepone contamination problem is scheduled for March 1978.

INTRODUCTION

The hazard of highly persistent, toxic substances contaminating large land and water areas is a problem of continuing concern worldwide. The Kepone problem in Hopewell, Virginia, was especially serious because of deleterious effects on the health of production workers. Two years after the closedown of the production site, the disposal of Kepone production residues is still not resolved. Inflows of Kepone into the James River and the levels of contamination in the river remain as high as those measured a year ago.

EPA's Kepone Mitigation Feasibility Project, undertaken at the request of the Governors of Virginia and Maryland, is designed to determine the nature, extent and effects of Kepone contamination in the James River System and to provide recommendations for mitigating actions.

BACKGROUND

Kepone was produced at Hopewell by the Allied Chemical Corporation from 1966 to early 1974, after which the Life Science Products Company, under contract to Allied, continued Kepone production. The plant was closed by Virginia public health officials in July 1975, after workers were diagnosed to have Kepone poisoning. Eventually more than 70 individuals developed ailments ranging from slurred speech and loss of memory to liver damage and sterility.

In July 1975, the Center for Disease Control at Atlanta, Georgia, analyzed blood samples of a Life Science Products Company employee and found a Kepone blood level of 7.4 $\mu\text{g/g}$. The State of Virginia in early August 1975 asked the EPA Health Effects Research Laboratory in North Carolina to institute a human and environmental sampling program to ascertain the extent and effects of Kepone contamination. EPA responded and reported its results on December 16, 1975. Kepone blood and sebum skin sample residues were found from 0.2 to 7.5 $\mu\text{g/g}$ from 28 hospitalized Life Science workers, and in one worker's hospitalized wife. Kepone was found in the James River water samples at concentrations of 0.1 to 4 $\mu\text{g/l}$ and in fish and shellfish at concentrations of 0.1 to 14 $\mu\text{g/g}$. Some water and shellfish samples were collected 40 and 64 miles from Hopewell, respectively. Action levels, recommended by EPA, for the condemnation of foods sold in the marketplace are 0.3 $\mu\text{g/g}$ for finfish, oysters and clams, and 0.4 $\mu\text{g/g}$ for crabs. Bottom sediments and sewage sludge contained significant Kepone concentrations. Prior to Life Science's closure, the Hopewell sewage treatment plant's digesters were made inoperable on several occasions because of the toxic effects of Kepone. Soils around the Life Science plant site had Kepone residues as high as 20,000 $\mu\text{g/g}$. Air samples gathered between March of 1974 and April 1975 from a State sampler station located approximately 200 meters from the Life Science plant contained residues ranging from 0.2 to 50 $\mu\text{g/m}^3$ of air.

On August 20, 1975, the EPA Regional Office in Philadelphia, Pennsylvania, issued an order to Life Science Products Company to stop sale, use or removal from its premises of Kepone. As a result of Kepone contamination, the Governor of Virginia closed the James River to fishing on December 18, 1975. On February

3, 1976, a stop sales order was issued to Allied Chemical's Baltimore facility, which served as the distribution point for the Kepone produced in Hopewell. A chronology of the major events to May 1976 is shown in Figure 1. The May 1976 Federal Court indictment led to a \$13.2 million fine against Allied Chemical.

The Kepone incident has had a disastrous effect on the Life Science workers and poses continuing hazards from Kepone contaminants in the soil, water and sediments. In addition to its human health and ecological damage, the Kepone incident has had an immediate economic impact on the James River fishermen and threatens an important seed oyster industry. The James River supplies approximately 90 percent of all seed oysters in Virginia, of which 50 percent are exported to other States.

KEPONE PROPERTIES AND USE

Kepone, technical grade Chlordecone ($C_{10}Cl_{10}O$), is a white-to-tan crystalline solid and sublimates at 350 degrees centigrade with decomposition. It is slightly soluble in water, soluble in acetone, ethers, and nitrobenzene, but less soluble in benzene, toluene, hexane, and petroleum ether. It can be dissolved by dilute alkali. Kepone during pyrolysis gives substantial quantities of hexachlorocyclopentadiene. When it reacts with phosphorus pentachloride, "Mirex" is produced, which is another chlorinated pesticide. Mirex may undergo a slow photodechlorination reaction when exposed to sunlight to produce Kepone and related compounds (1).

Kepone was used in the United States as an ant and roach killer. It is used in other countries on potato beetles, banana bore worms and fire ants. Approximately 90 percent of Life Science's Kepone production was exported. Kepone is related to the chemicals DDT, Aldrin and Dieldrin, all of which have been restricted in their use by the Environmental Protection Agency. Kepone registration has been cancelled except for the use of small percentages of Kepone by pesticide formulators in ant and roach traps until present stocks are used.

KEPONE CONTAMINATION IN THE HOPEWELL AREA

Hopewell, Virginia, situated at the junction of the James and Appomattox Rivers, has manufactured chemicals since the World War I era. Today, it is a major chemical preparation center of 23,300 people (Figure 2).

The amount of Kepone lost from the Life Science operation has been estimated to be as much as 91,000 kg (200,000 lb.) with Kepone production estimated to be approximately 770,000 kg (1,700,000 lb.) (2). These losses were derived largely from four basic sources: (1) atmospheric release, (2) wastewater discharges; (3) wastewater releases from spills, equipment malfunctions, and production batches that failed to meet specifications; and (4) tank truck and solid waste loads dumped at the Hopewell landfill. The magnitude of these sources cannot accurately be quantified. Spillage from the production line and intentional discharges constitute the biggest nonquantifiable source of releases.

Kepone Chronology

Year	Others	Allied Chemical Corporation	Life Sciences Products Company (LSP)	City of Hopewell, Virginia	State of Virginia	Environmental Protection Agency (EPA)	Occupational Safety and Health Administration (OSHA)
1959			Kepone first registered as a pesticide with USDA. Toxicity information included in registration shows Kepone causes "DDT-like tremors."				
1960 to 1972			Kepone found to cause growth and reproductive effects and tumors. 1966: Manufacture begins at Allied plant in Hopewell.			1971: EPA assumes responsibility for registration and regulation of pesticides from USDA.	December 1970: Occupational Safety and Health Act creates OSHA.
1973		Allied terminates Kepone production.	LSP Incorporates in Virginia and contracts with Allied to produce Kepone from raw material supplied by Allied for sale exclusively to Allied at the rate of 0.4 to 1.5 million pounds per year.	October: Application to Water Control Board for a permit to discharge municipal waste water. Claims no industrial charges enter sewage treatment plant.			
1974			February: After citation for failure to obtain air pollution permit LSP applies for and receives permit. Repeated violations of standard for particulates require installation of baghouse in October.	April: After discovery that the sewage treatment plant is malfunctioning because of decimation of bacterial digesters by Kepone, Hopewell asks EPA for toxicity and treatment information.	February: Virginia cites LSP for failure to obtain air pollution permit for SO ₂ and particulates. (See LSP listing.) October: Water Control Board grants Hopewell waste water permit with no requirements for monitoring or limit on Kepone discharges, but solicits information and recommendations for treatment of Kepone contamination from EPA. (See Hopewell listing.)	November: EPA provides information requested by Water Control Board on toxicity of Kepone and recommends a limit of 0.4 part per billion in water for municipal plant intake.	September: Former LSP employee files a complaint about working conditions at LSP. OSHA's toxicological information does not indicate severe hazard so complaint handled as discrimination case.

Kepone Chronology

Year	Others	Allied Chemical Corporation	Life Sciences Products Company (LSP)	City of Hopewell, Virginia	State of Virginia	Environmental Protection Agency (EPA)	Occupational Safety and Health Administration (OSHA)
1975	July: Hopewell physician submits blood sample of LSP employee to Center for Disease Control (Atlanta) for analysis. CDC finds Kepone blood level of 7.4 ppm and notifies Virginia Department of Health. August: Washington Post reports illness of Kepone workers and LSP closing.	March 20: Expecting new regulations. Allied applies for registration under FIFRA(b) of LSP as manufacturer of a pesticide. April 11: Allied letter to EPA asserts that under existing regulations Kepone produced at LSP is a pesticide component; therefore, LSP is not subject to FIFRA's pesticide producer registration requirement.	July: Virginia State Health Department orders LSP to stop production. Limited production continues into September. December: EPA analyzes air samples obtained earlier by Air Pollution Control Board and finds Kepone among the pollutants collected.	April: City agrees with Water Control Board to clean and repair water treatment facilities by June. June: Above dead-line not met.	June: State amends Hopewell waste water permit to require pretreatment of effluents from LSP. Requirements apparently ignored. July: Virginia Department of Health receives report of Kepone blood levels in LSP employees. State inspects LSP and orders it to close. December: Governor of Virginia closes James River to fish and shellfish harvesting.	March: EPA begins to investigate whether LSP has violated FIFRA (a) requirement that all pesticide products and producers register with EPA. August: EPA begins human and environmental sampling of Hopewell area. September: EPA informs FDA of James River contamination. December: EPA reports results of sampling program.	August: OSHA officials first visit Hopewell, where Kepone production continues despite state order to close. OSHA cites LSP and the two LSP copartners for 4 violations, including failure to prevent employee exposure to harmful levels of Kepone. The total proposed penalty for the violation is \$16,500.
1976	February: Medical College of Virginia reports that 14 former LSP employees are probably sterile. National Cancer Institute releases study results indicating Kepone is carcinogenic. March: FDA establishes action levels for seizure of contaminated fish and shellfish.	May: Allied Chemical, Life Sciences, and the City of Hopewell are indicted in federal court on 1,096 criminal counts, including conspiracy to defraud EPA and violations of federal water pollution laws.				February: EPA recommends action levels to FDA for seizure of contaminated fish and shellfish. March: EPA sends formulators of Kepone-containing products a notice of presumption against registration of these products.	January: OSHA reopens 1974 complaint of former employee of LSP.

(a) Information obtained from EPA, Senate Agriculture and Forestry Committee (hearings before the Subcommittee on Agricultural Research and General Legislation, Jan. 22, 23, 26 and 27, 1976).

(b) Federal Insecticide, Fungicide, and Rodenticide Act, as amended.

Figure 1.

Kepone Chronology. Environmental Quality-1976: The Seventh Annual Report of the Council on Environmental Quality, Washington, D.C.

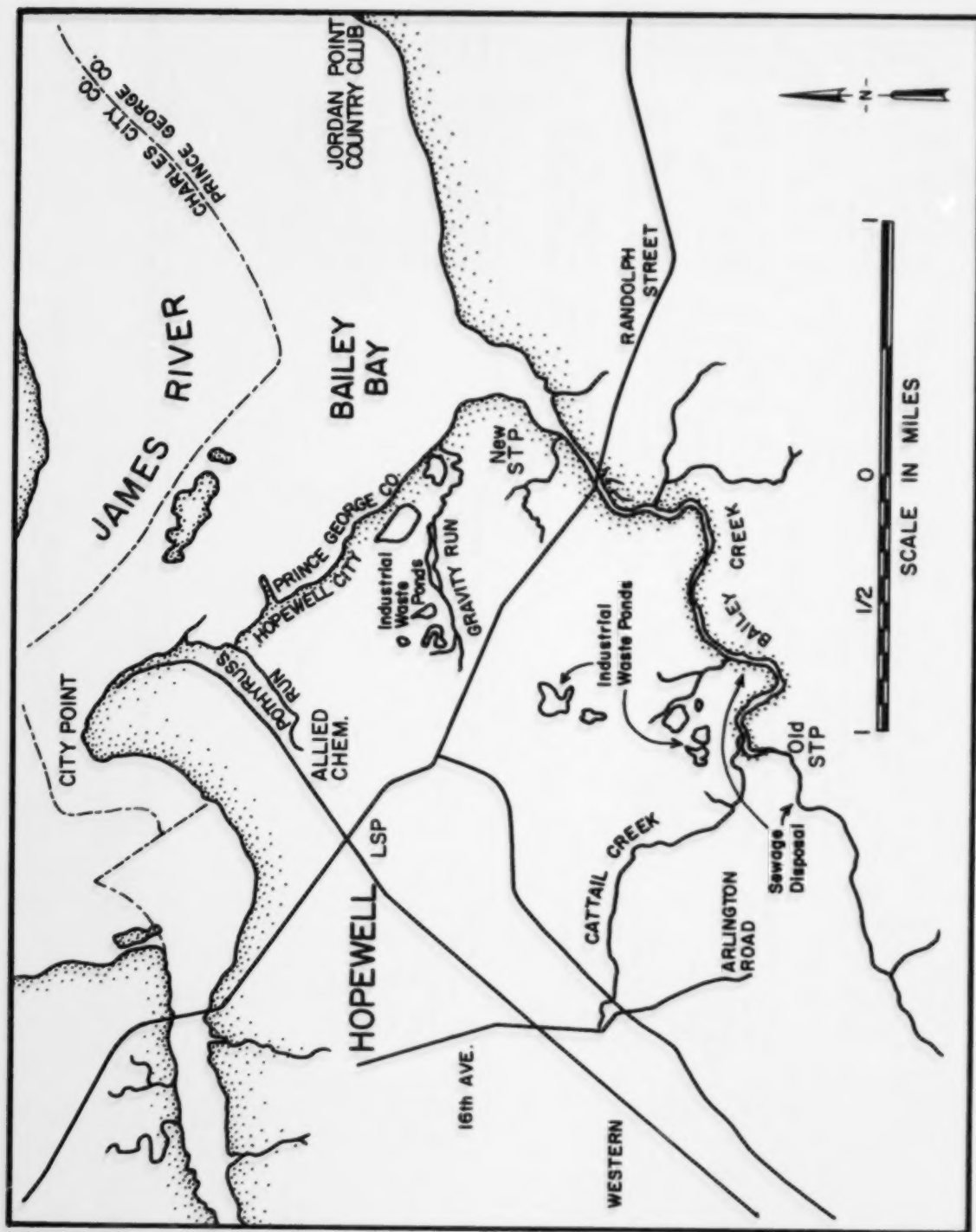


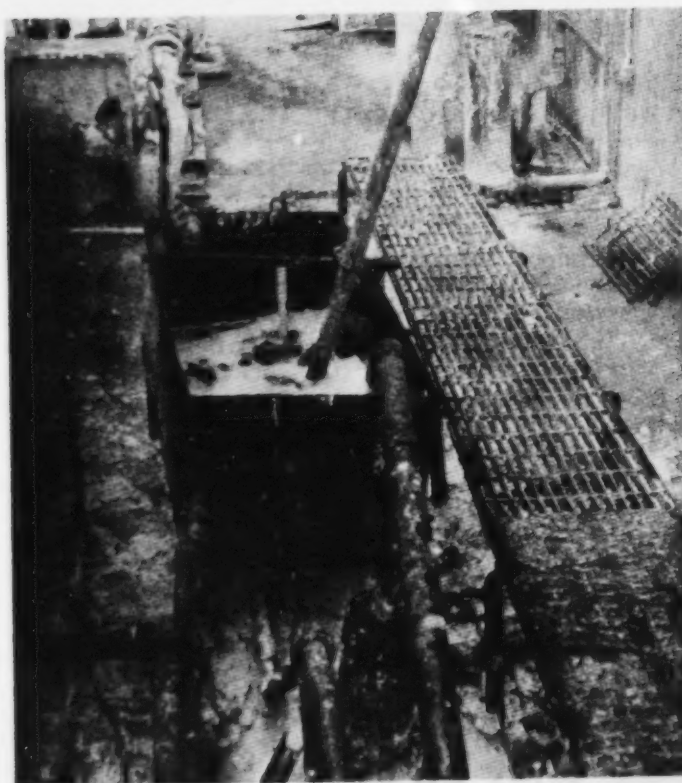
Figure 2. Hopewell, Virginia and Bailey Bay/James River (from U.S. Geological Survey, Washington, D.C.)

Grand Jury testimony by former Life Science employees indicated there were three major sources of spills. The first source was routine spills of overflows and boil-overs. The second was discolored Kepone or batches not meeting Allied specifications which were dumped directly into the sewer. Employee testimony suggests that this occurred approximately once a week in the early plant operation and once a month thereafter. The final source was bypassing or dumping of filter tanks. These loads of Kepone caused the Hopewell sewage treatment plant to be inoperable on several occasions. Figure 3 shows the Life Science plant after closure. During cleanup and after the Life Science closure, Kepone-contaminated sludge from the sewage treatment plant was placed in an asphalt gravel-lined, earthen-diked lagoon near the plant. Estimated volume of the lagoon is 5,700 cubic meters (1.5 million gallons) with the liquid portion containing approximately 2 mg/l Kepone and the solids 200 to 500 µg/g (3). Remnants from the dismantled Life Science plant were placed in a clay-lined pit in the landfill adjacent to the sewage treatment plant (4).

KEPONE MITIGATION FEASIBILITY PROJECT

The Governors of Virginia and Maryland, in the Fall of 1976, jointly requested that EPA evaluate the Kepone contamination in the James River and its tributaries, and explore corrective or mitigative actions. In response to this request, a two-phase project plan was adopted. Phase I involves a detailed assessment of: (1) suspected continuing sources of Kepone contamination; (2) the fate and transport of Kepone in the James River system; (3) the current and long-range effects of Kepone contamination on the biota; and (4) an evaluation of mitigation and removal methods. The results of Phase I are to provide a basis for action recommendations. Following a review of the Phase I recommendations by EPA and the States of Virginia and Maryland, Phase II may involve a decision to: seek funding for a major cleanup or mitigation program; proceed with pilot testing of alternative corrective and mitigative actions; or withhold action because of unfavorable cost/benefit assessments.

An allocation of \$1.4 million was made for the Phase I effort. A comprehensive work plan was developed and support studies were arranged with the U. S. Army Corps of Engineers, the Energy Research and Development Agency (ERDA), the EPA Gulf Breeze, Florida, Environmental Research Laboratory, and the Virginia Institute of Marine Science. Under the interagency agreement with the Norfolk, Virginia, District Corps of Engineers, engineering studies to contain, stabilize, or remove Kepone-contaminated sediments have been conducted. Eighteen alternatives to mitigate the Kepone problem have been evaluated. In addition, the Corps of Engineers has contracted with the U. S. Fish and Wildlife Service to investigate the wetland ecosystem to compare plant and animal distribution patterns with unaffected areas. Under the interagency agreement with ERDA, the ERDA/Battelle Pacific Northwest Laboratories are: (1) conducting sampling and analysis of the suspected sources of Kepone contamination to the James River; (2) obtaining in cooperation with the Virginia Institute of Marine Science, water quality, sediment, hydrological and other data on the James River; (3) modeling the transport and fate of sediments in the river; (4) evaluating nonconventional Kepone mitigation techniques; and (5) assessing the ecological impact of the current Kepone contamination and possible mitigation approaches. The EPA Gulf Breeze Laboratory provided scientific data and



(Top) Life Science Products in Hopewell, Virginia, produced Kepone until July 1975 when it was closed down by the state. (Bottom) The collection box shown has a drainpipe with cracks in its side, allowing Kepone to leak into the city's sewer system. Such contaminating conditions led to the poisoning of many of the plant's employees (Photo credit: Virginia State Department of Health, Dr. Robert S. Jackson)

Figure 3. Life Science Products Company

analysis on the effects of Kepone on the estuarine biota, including bioaccumulation, and distribution and fate of Kepone. The Virginia Institute of Marine Science is collecting field data on the James River. Results of these investigations are being integrated into models of Kepone movement and sediment transport by Gulf Breeze and ERDA/Battelle Laboratories, respectively (Figure 4). Key milestones in task plans included presentation and discussion of preliminary results at a Kepone Seminar in September 1977, draft reports from the supporting agencies in November, a draft Kepone Mitigation Feasibility Report in January 1978, and a final report with recommendations in March 1978. The final report will be the basis for considering the Phase II efforts.

KEPONE ANALYTICAL PROCEDURE AND STANDARDIZATION

Selection of a reliable, well-accepted analytical procedure for detecting and establishing levels of Kepone was essential. Accordingly, the procedure developed by EPA at Research Triangle Park, North Carolina, was adopted (5). This procedure accommodates analyses of river sediment, soil, water, shellfish, and finfish. Rigorous extraction techniques utilizing the Soxhlet apparatus and the Polytron tissue homogenizer are required for the complete removal of Kepone from the samples. Finfish tissues are the most difficult to analyze. For this type of substratum, a preliminary cleanup by gel permeation chromatography removes most of the lipid material followed by a micro Florisil column elution to eliminate polychlorinated biphenyls (PCBs). Cleanup of shellfish and other environmental samples is accomplished with a micro Florisil column only. Electron capture gas chromatography is used to analyze the sample extracts. Recoveries of Kepone from fortified samples averaged 84 percent or greater.

To assure quality control between investigating laboratories, the Kepone Mitigation Feasibility Project instituted a standardization procedure involving the distribution to participants involved with Kepone analyses of samples containing Kepone concentrations unknown to them. Four sample groups were distributed: (1) control without Kepone; (2) control known to have interfering compounds; (3) James River Kepone-contaminated sample; and (4) fortified sample of known Kepone quantity. Presently the results are being analyzed and recommendations for improved laboratory procedures will be instituted, if necessary.

TOXICITY

Kepone is toxic to animals causing liver enlargement, impaired reproduction, and endocrine disturbances. In mice it is accumulated mainly in the liver, brain, kidney and body fat (6, 7). It also has been reported to be carcinogenic in mice and rats (8).

Kepone is extremely hazardous to the reproductive capacity of male birds by exerting an "estrogen-like" effect. Male ring-necked pheasants fed Kepone at 50, 100, or 150 $\mu\text{g/g}$ developed adult female plumage and had abnormal testes with malformed sperm (9). Degeneration and abnormality of testes also has been noted in Japanese quail in immature, as well as adult males (10, 11, 7). In some cases testes were greatly enlarged with distended seminiferous tubules filled with fluid and cellular debris disrupted germinal epithelium and decreased spermatogenesis. In all other cases testes were severely atrophied in

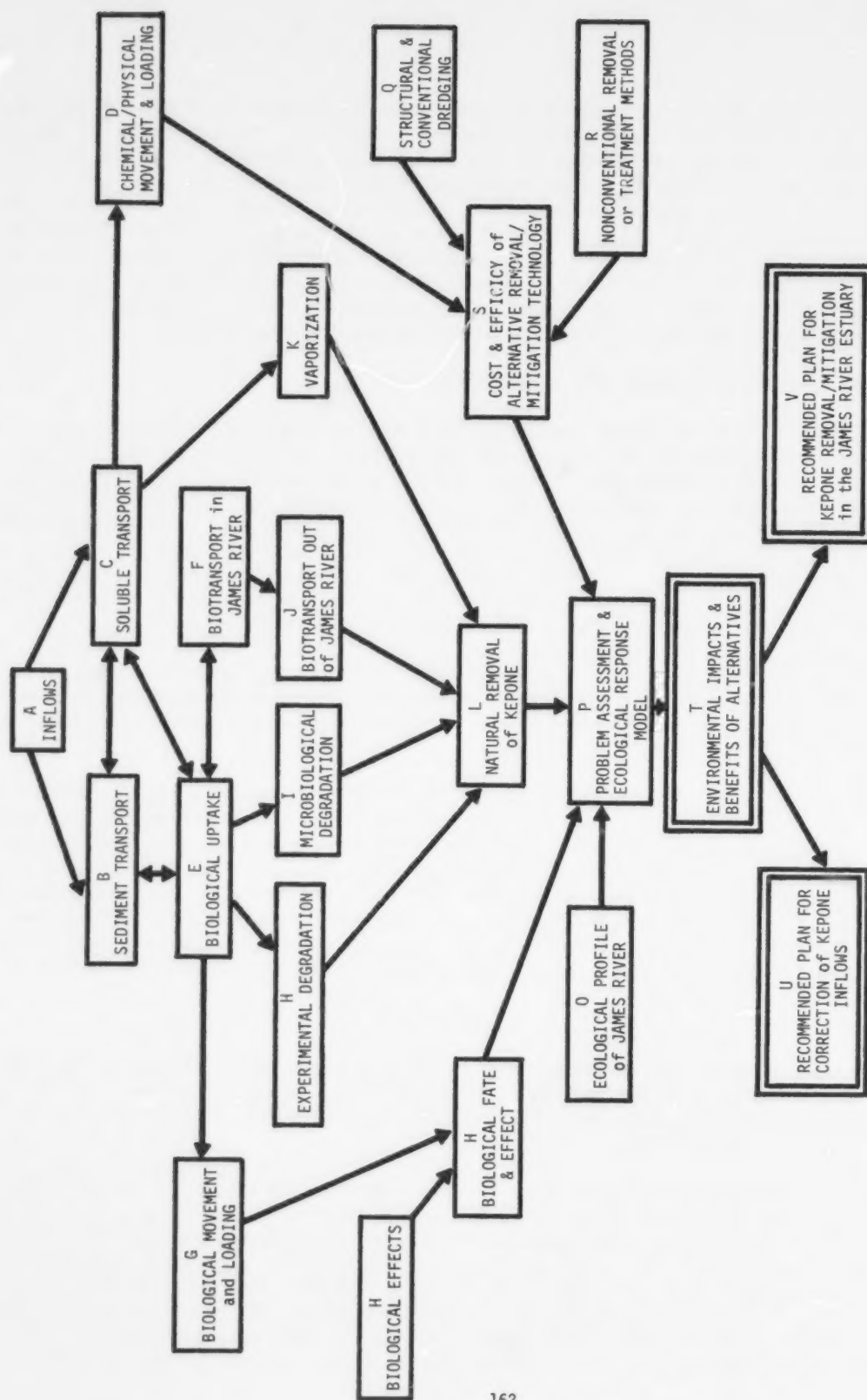


Figure 4. Kepone mitigation feasibility project components.

a manner similar to testes of estrogen-injected birds. Cows fed 5.0 µg/g Kepone in their diets for 60 days excreted 90 µg/g of Kepone in their milk 35 days after the end of the feeding experiment (12). Dr. Rita Colwell, University of Maryland, maintains that there may be several bacteria which may degrade Kepone.

The EPA Gulf Breeze, Florida, Environmental Research Laboratory has found that (13, 14, 15, 16, 17):

- Oysters, grass shrimp and certain species of fishes have bioaccumulated Kepone from 425 to 20,000 times the concentrations in the surrounding water;
- Kepone-contaminated oysters, when placed in Kepone-free water can depurate approximately 90 percent of the accumulated Kepone in four days, but fish may require 3 weeks or more to lose 30 to 50 percent of the Kepone.
- Fifty percent photosynthetic reduction for four marine unicellular algae exposed to Kepone for seven days ranged for 0.35 to 0.60 mg/l;
- Acute 96-hr LC50 toxicity of Kepone on spot, sheepshead minnow, grass shrimp and blue crab ranged from 6.6 to greater than 210 µg/l, with 6.6 µg/l being associated with spot.
- Sheepshead minnows (Cyprinodon variegatus) during chronic toxicity tests exhibited backbone structural abnormalities (scoliosis), darkening of the posterior one-third of the body, hemorrhaging near the brain and on the body, edema, fin-rot, uncoordinated swimming and cessation of feeding; and
- Fish fry from Kepone-exposed parent stock, developed abnormally and died even when reared in Kepone-free water. Five weeks after fertilization of sheepshead minnow eggs containing Kepone, the juvenile fish retained as much as 46 percent of the Kepone originally present in the eggs.

Kepone recently has been tested under the auspices of the National Cancer Institute (8). Osborne-Mendel rats and B6C3F1 mice were fed Kepone in their diets for 80 weeks and developed malignant liver tumors (hepatocarcinomas) when the diet contained 20 and 40 µg/g Kepone.

HOPEWELL AREA SAMPLING

A comprehensive sampling plan for Bailey Creek, Gravelly Run, and other water courses, plus the terrestrial areas of the City of Hopewell, the municipal sewage treatment plant area, and the municipal landfill, was established to quantify inflows of Kepone to Bailey Bay and the James River system. Soil samples were taken at various locations in the Hopewell area to determine the extent of Kepone contamination in the watersheds. The sampling points were located to give insight to the possible significance of contamination of the

James River from terrestrial sources. Representative sampling sites in the Hopewell/Bailey Bay area are shown in Figure 5 with the results of this sampling shown in Figure 6.

The levels of Kepone contamination at the Life Science production site have dropped substantially from the 1975 levels of 10,000 to 20,000 $\mu\text{g/g}$. Results of field investigations indicate about 200 $\mu\text{g/g}$ Kepone in soil samples in the vicinity of the now unused production plant. Most soil samples in the surrounding Hopewell area, however, are close to a level of 0.25 $\mu\text{g/g}$. Kepone as high as 386 $\mu\text{g/l}$ has been found in storm runoff from the production plant site. Area test wells close to the plant site contained 0.8 $\mu\text{g/l}$ Kepone.

Homogenized one-third meter core samples of Bailey Bay sediments have been found to have Kepone concentrations of 12.6 $\mu\text{g/g}$ near the mouth of Bailey Creek to about 0.1 $\mu\text{g/g}$ in the outer portions of the Bay. Sediment Kepone concentrations generally are highest along the shore of Bailey Bay, as would be expected from the settling action produced by James River flow. Within sediment cores from Bailey Bay near the debouchment of Bailey Creek, there was great variation in the vertical levels of the core. At the core's surface there was 0.81 $\mu\text{g/g}$ Kepone; at the 7-inch level, 65.14 $\mu\text{g/g}$; and at the 10-inch level 0.45 $\mu\text{g/g}$. This phenomenon remains unexplained.

Kepone is preferentially associated with the larger organic particles in the sediment. This observation coincides with those made by Allied Chemical and Virginia Institute of Marine Science and suggests that detrital matter may be an important role in the binding and transport of Kepone (18, 19).

JAMES RIVER SAMPLING

The purpose of the James River sampling plan was to obtain field data in the James River for input to and adjustment of the sediment and contaminant transport model and for derivation of fractionation coefficients for dissolved and sediment sorbed Kepone in the James River.

This original sampling plan consisted of data acquisition at ten transects along a 70-mile reach of the James River and estuary. Three stations were located on each transect (one station in the flow channel and one station each on either side of the flow channel on the subtidal flats or channel margins). One to three depths were sampled per station (near surface mid-depth and near bottom). Four transects were located in the freshwater reach of the James River between River Mile (R.M.) 45 and 70, three transects in the saline water or estuarine section between R.M. 0 and 35, and three transects in the turbidity maximum between R.M. 35 and 45.

The sampling data gathered in the field include meteorological and hydrological information; channel and flow characteristics, physical and chemical characteristics of suspended load and bed sediments; and water quality characteristics. Kepone analyses were conducted on water, suspended load and bottom sediment samples. Figure 7 shows the relative sediment concentrations of Kepone for the 70-mile reach of the river sampled in 1976.

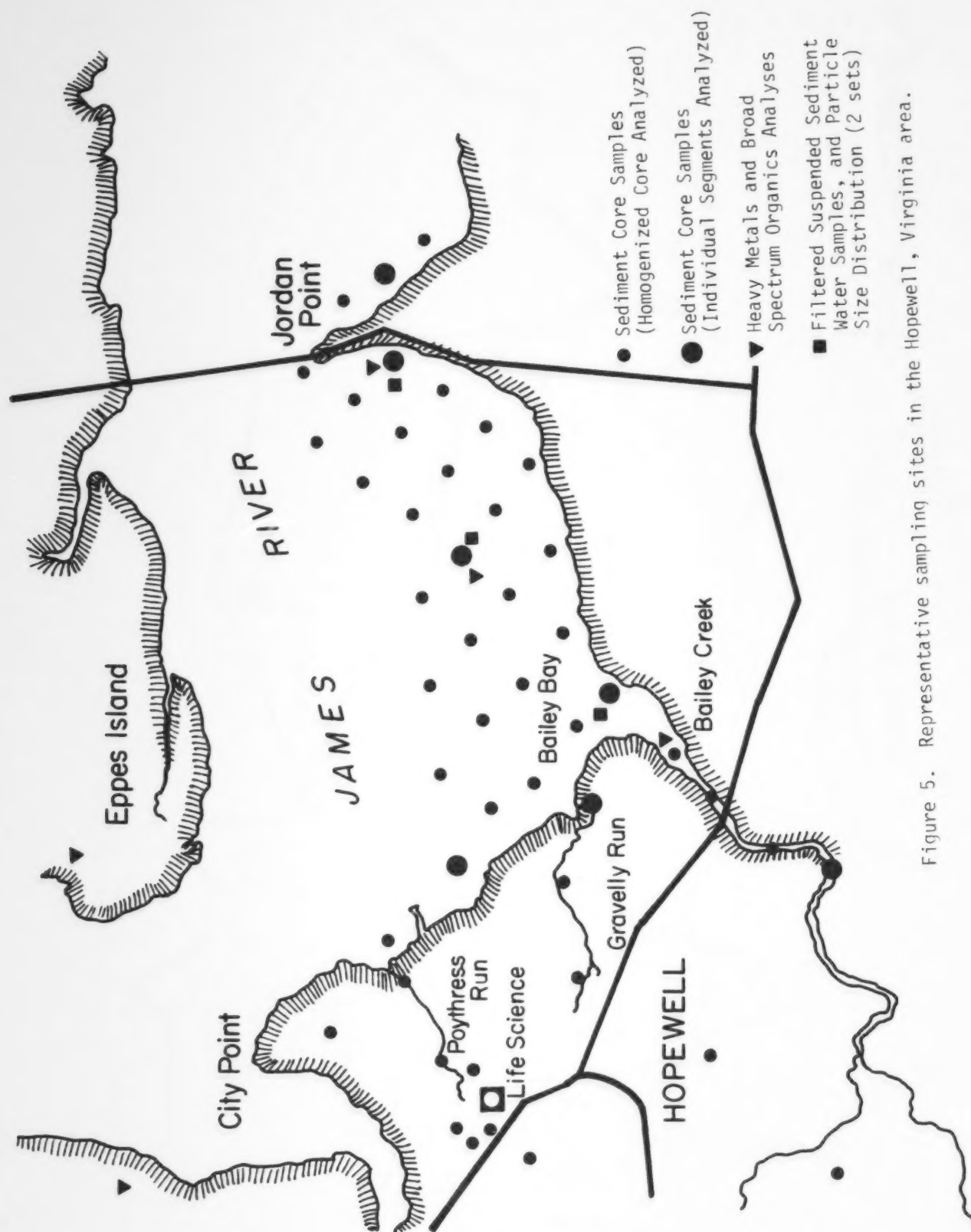
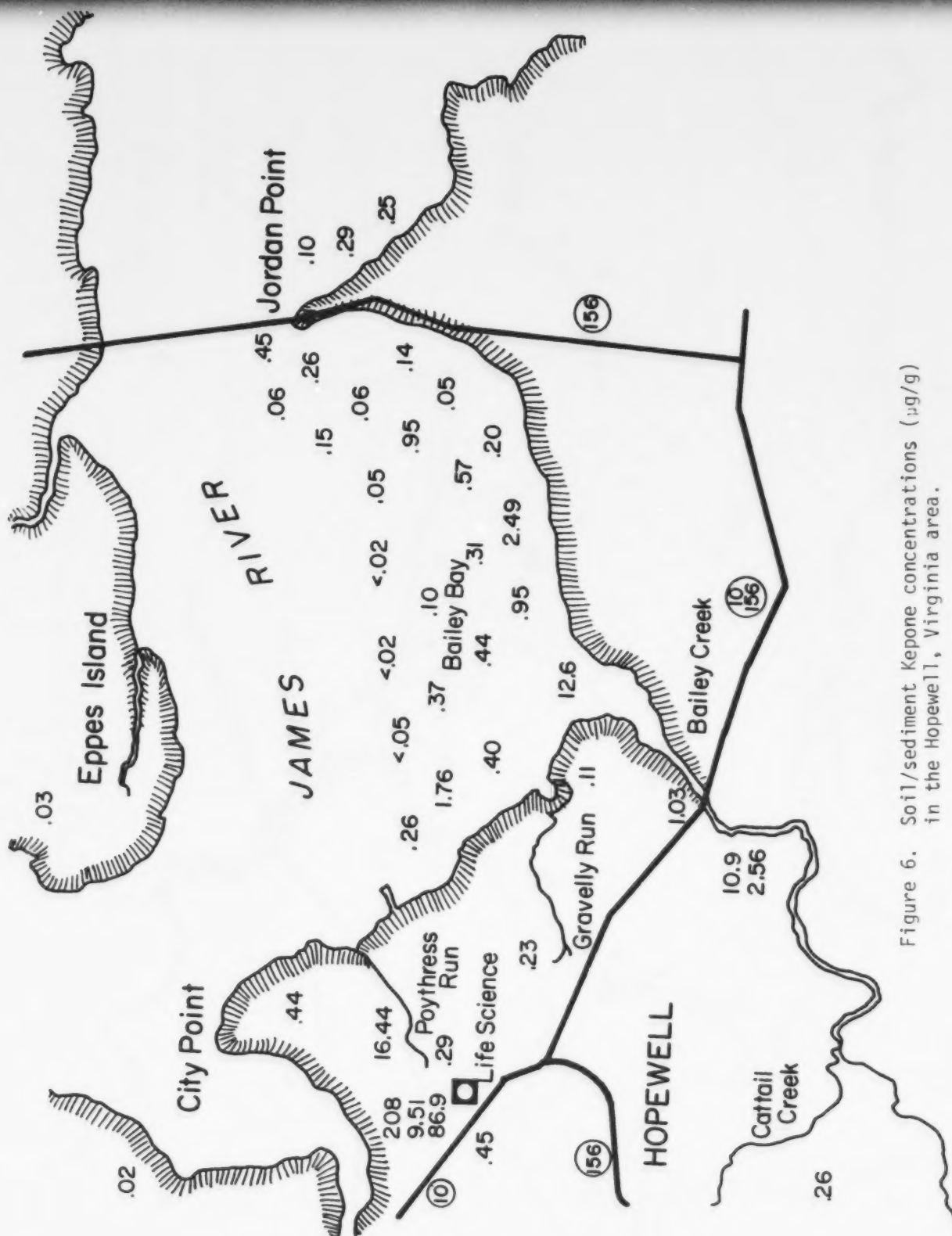


Figure 5. Representative sampling sites in the Hopewell, Virginia area.



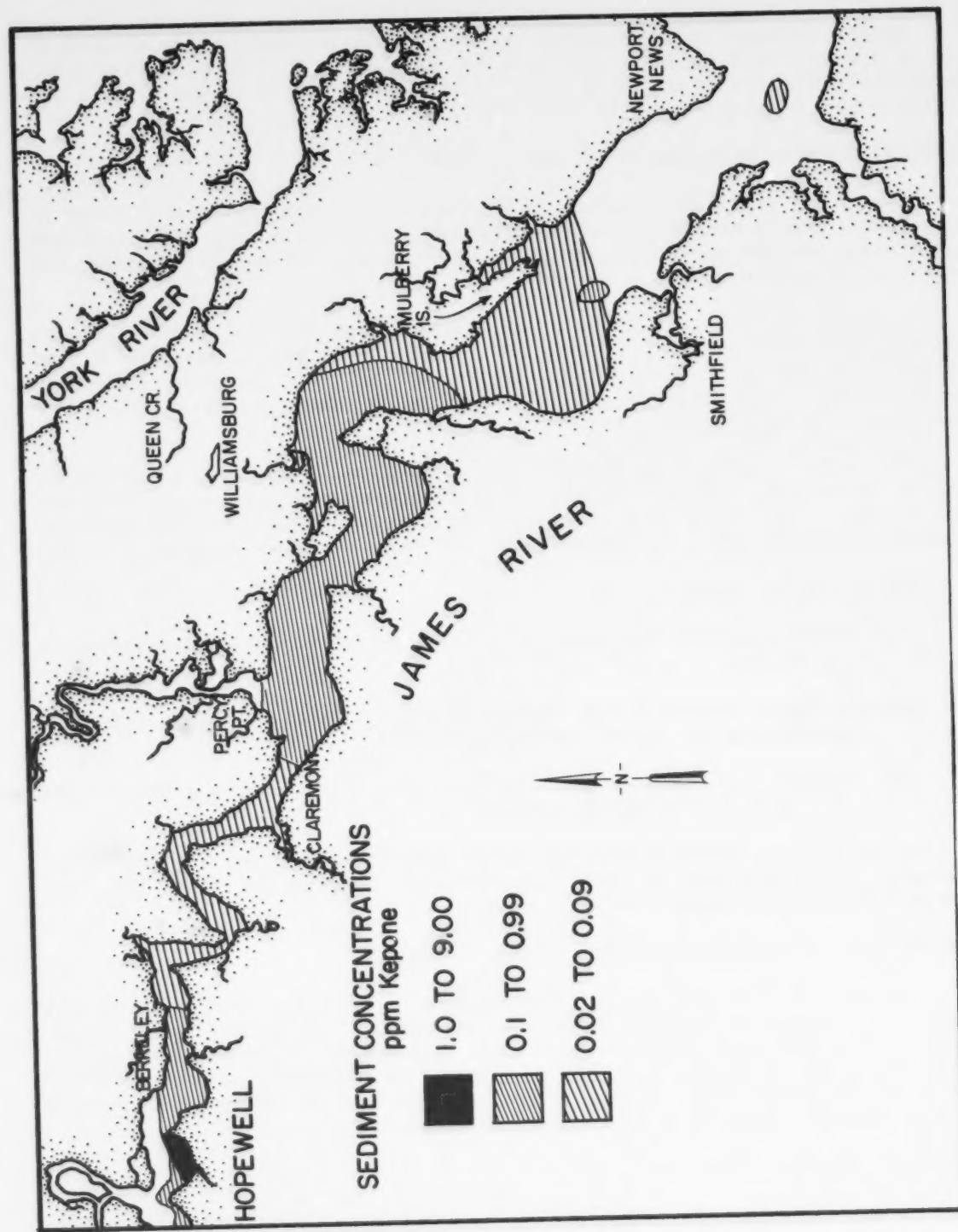


Figure 7. James River sediment concentrations from Hopewell, Virginia to Newport News, Virginia. August 1976

Kepone sediment concentrations in the James River ranged from a level of 1.0 to 9.0 $\mu\text{g/g}$ near Hopewell and in Bailey Bay to 0.1 to 0.99 $\mu\text{g/g}$ in a reach immediately downstream and in a reach of more quiet waters in the river's mid portions to 0.02 to 0.09 $\mu\text{g/g}$ in other reaches.

MODELING MOVEMENT OF KEPONE IN THE JAMES RIVER

One of the critical questions to be addressed by the feasibility study is whether the Kepone contamination from the James River is moving downstream and threatening the Chesapeake Bay and if so, at what rate and what are the expected levels of contamination.

A model has been developed to address this problem. The model simulates the movement and resulting distribution of Kepone in the 70-mile reach from Hopewell to the mouth of the James River. The data for the model have been derived from a wide range of previous sampling programs, together with those conducted in this project.

The model combines parameters for a riverine system and an estuarine system reflecting: seasonal flows; tidal fluctuations; vertical and horizontal mixing of both water and sediments; the effects of the turbidity maximum; sediment transport; and sorbtion/desorbtion of Kepone from sediments.

Outputs of the model include:

- (1) time-dependent, longitudinal and lateral distributions of sediments and Kepone;
- (2) sediment transport for three sediment types: cohesive sediment, noncohesive sediments, and organic materials, and;
- (3) Kepone transport for the dissolved portion and for the particulate portion which has Kepone attached.

At this time, complete results of the modeling effort are not available; however, preliminary findings tend to confirm the movement of higher levels of Kepone concentration downstream.

CONVENTIONAL MITIGATION TECHNIQUES

The Norfolk District Office of the Corps of Engineers is evaluating all potential dredging technology, as well as methods to reduce and control resuspension of concomitant secondary pollution. Subsequent to this evaluation the Corps was asked to develop conventional removal or mitigation alternatives for reducing the Kepone contamination in Bailey Creek and Bailey Bay and to prepare an environmental assessment addressing these alternatives.

POTENTIAL DREDGING TECHNOLOGY

In the United States today there are basically two categories of dredges, the scoop or bucket action type and the hydraulic suction type. Often considerable turbidity is created at the dredge site during operation of these

types of dredges. Bucket action or scoop dredges used in the U. S. include the dragline, the dipper, the grab bucket or clamshell and the endless chain dredge. Hydraulic suction type dredges consist of a surface mounted centrifugal pump which sucks water and suspended material through a pipeline, floated on pontoons, to a disposal site or holding containers which, when full, transport the spoil to a disposal site.

The hydraulic suction dredge can be fitted with various mechanisms at the suction pipe inlet which facilitate sediment removal. These mechanisms include rotary cutters or cutterheads, auger-type cutter heads or high pressure water jets. Mud shields or dustpans are used on some hydraulic dredges in conjunction with the water jets to reduce secondary suspension at the suction inlet. However, these dredges collect only 10 to 30 percent solids, cause considerable sediment agitation when mechanical cutterheads are used, and induce secondary pollution at the receiving site due to high water content in the dredged material. Consequently, without the use of sediment control measures such as silt curtains, turbidity barriers or "diapers", conventional dredges pose a serious threat for aggravating an existing, but possibly dormant pollution problem. Some types of hydraulic dredges in the U. S. include the cutterhead pipeline, the suction pipeline, the dustpan, the hopper hydraulic dredge, the sidecasting dredge, and the Mud Cat.

Dredging technology in foreign countries surpasses that of the U. S., especially in Japan where serious problems with toxic substances caused the development of a dredge which was designed to remove contaminants rather than to excavate river channels. A significant advancement in dredging technology for removing contaminants was the improvement of a pneumatic dredge. The pneumatic or "Pneuma" dredge, originally developed in Italy, uses hydrostatic head pressure and compressed air to remove contaminated sediments. By applying a vacuum to a pneumatic dredge the Japanese were able to utilize the dredge in shallow water, thereby eliminating the constraint of needing a high hydrostatic head pressure. This dredge is called the Oozer dredge.

Specific advantages for using the pneumatic dredge system especially for contaminant removal include:

- (1) continuous and uniform flow;
- (2) practically no wear since there are no mechanisms in contact with the abrasive mixture except for the self-acting spherical rubber valves;
- (3) removes up to 60 to 80 percent solids by volume;
- (4) particularly suited for dredging polluted material since it does not disturb the bed while dredging and therefore avoids secondary pollution; and
- (5) can be readily dismantled for transport over highways.

The following are examples of the pneumatic-type dredges: Pneuma (Italy), Pressain Sand-Pump (Germany) and Oozer (Japan).

The Japanese have also advanced other aspects of dredging technology through the development of a "cleanup" hydraulic dredge, an antiturbidity system for hopper dredges and the water-tight grab bucket.

ALTERNATIVE CONVENTIONAL MITIGATION MEASURES FOR CAPTURING, STABILIZING, OR REMOVING KEPONE IN GRAVELLY RUN, BAILEY BAY, AND BAILEY CREEK

In considering any dredging activity, it is important to address the method of conveyance and the disposal area for the dredged material. These components need to be considered as an integrated system and not as separate components. With the complication of contaminated sediment the problem greatly magnifies. Considering the Hopewell situation the Corps developed 18 alternative measures to manage the Kepone contamination in Gravelly Run, Bailey Creek, and Bailey Bay. The Corps' alternatives consisted of diking, dredging, covering or sealing, impoundment, channelization and diversion, or combinations thereof. After evaluating each alternative some were eliminated from further consideration because they offered no further benefits over less costly options. It must also be noted that treatment of water leaving Bailey Bay or Bailey Creek is necessary and these costs have not yet been considered in the alternatives.

Bailey Bay, near Hopewell, is situated between Jordan Point to the east and City Point to the west. It is approximately 2.4 miles long, 1/2 mile in width, and encompasses about 800 acres. Both Bailey Creek and Gravelly Run discharge into Bailey Bay. The Bay, for the most part, is shallow. At extreme low tides, almost the entire bay bottom is exposed. A few small vegetated islands exist in the northern portion of the Bay.

Bailey Creek, which discharges into Bailey Bay, has a drainage area of approximately 20 square miles. The creek is 3.2 miles in length from the mouth to Route 156, about 700 feet wide at the mouth, and about 25 feet wide at Route 156. Two bridges cross the creek, Route 156 and Route 10. Of the 20 square-mile drainage area, 14 square miles is upstream from Route 156. Both the east and west banks of Bailey Creek are highly wooded throughout the study area.

Gravelly Run also drains into Bailey Bay and has a drainage area of about 1 square mile. The Corps is considering 4 basic mitigation options for Gravelly Run:

- (1) A dam and treatment plant at the mouth of Gravelly Run to treat flows up to and including the 100-year flood level. The treatment plant would be designed for 50 to 150 million gallons per day (MGD), depending on the detention time allotted. This option would require 72 acres and cost \$1.5 million, excluding treatment costs.
- (2) Dam mouth of Gravelly Run, exclude spillway and divert all existing flow to Bailey Creek for treatment. Costs would be \$2 million, excluding treatment costs.

- (3) Seal contaminated areas, elevate stream channel, rip rap creek bed and construct control structure at mouth. Costs would be \$1.8 million.
- (4) Dredge all contaminated material from Gravelly Run. Twenty acres would need clearing prior to dredging, and a treatment plant would be needed to treat dredging effluent.

Four similar alternatives are still being considered for Bailey Creek:

- (1) A dam and treatment plant at the mouth to treat flows including the 100-year flood level. The cost would be \$14 million, excluding treatment costs.
- (2) Seal contaminated sediments, rip rap creek bed, elevate channel and construct control structure at mouth. This option would cost \$20 million.
- (3) Dredge all contaminated material from Bailey Creek. 410 acres would need clearing and 2.2 million cubic yards of material would need excavating.
- (4) Dam and divert upland uncontaminated watershed flows to reduce size of dam and treatment plant needs at the mouth. The upstream reservoir would require 1,405 acres of land. Diversion to Chappell Creek would require pumping and \$35 million while diversion to Bailey Bay in sealed pipe paralleling the existing flows would cost \$23 million.

The options for Bailey Bay are more significant because of the area's size and the amount of contaminated sediments. The Corps is considering five alternatives for Bailey Bay:

- (1) Dredge contaminated material from Bailey Bay and dispose of spoil at an estuarine or upland site. No final spoil site or costs have been determined. Dredging to obtain Kepone levels of 0.3 $\mu\text{g/g}$ would require removing 2.8 million cubic yards of sediment while dredging to 0.1 $\mu\text{g/g}$ levels would require removing 4.3 million cubic yards of material. Treatment of elutriate water would be required in both cases.
- (2) Construct a levee from 1 mile east of City Point to Jordan Point a distance of 14,250 feet. This levee would contain all the runoff from Gravelly Run and Bailey Creek, would be 10 feet above mean sea level (MSL) and would cost \$8 million, excluding treatment. This option is illustrated in Figure 8.
- (3) Construct high dams on Bailey Creek and Gravelly Run, divert flows from Gravelly Run to Bailey Creek. Treat runoff at Bailey Creek and store dredged material from Bailey Bay behind the dam on Bailey Creek. Treatment requirements would be from 100 to 150 MDG depending on retention times. This option requires 930 acres and would cost more than \$21 million, excluding treatment costs.

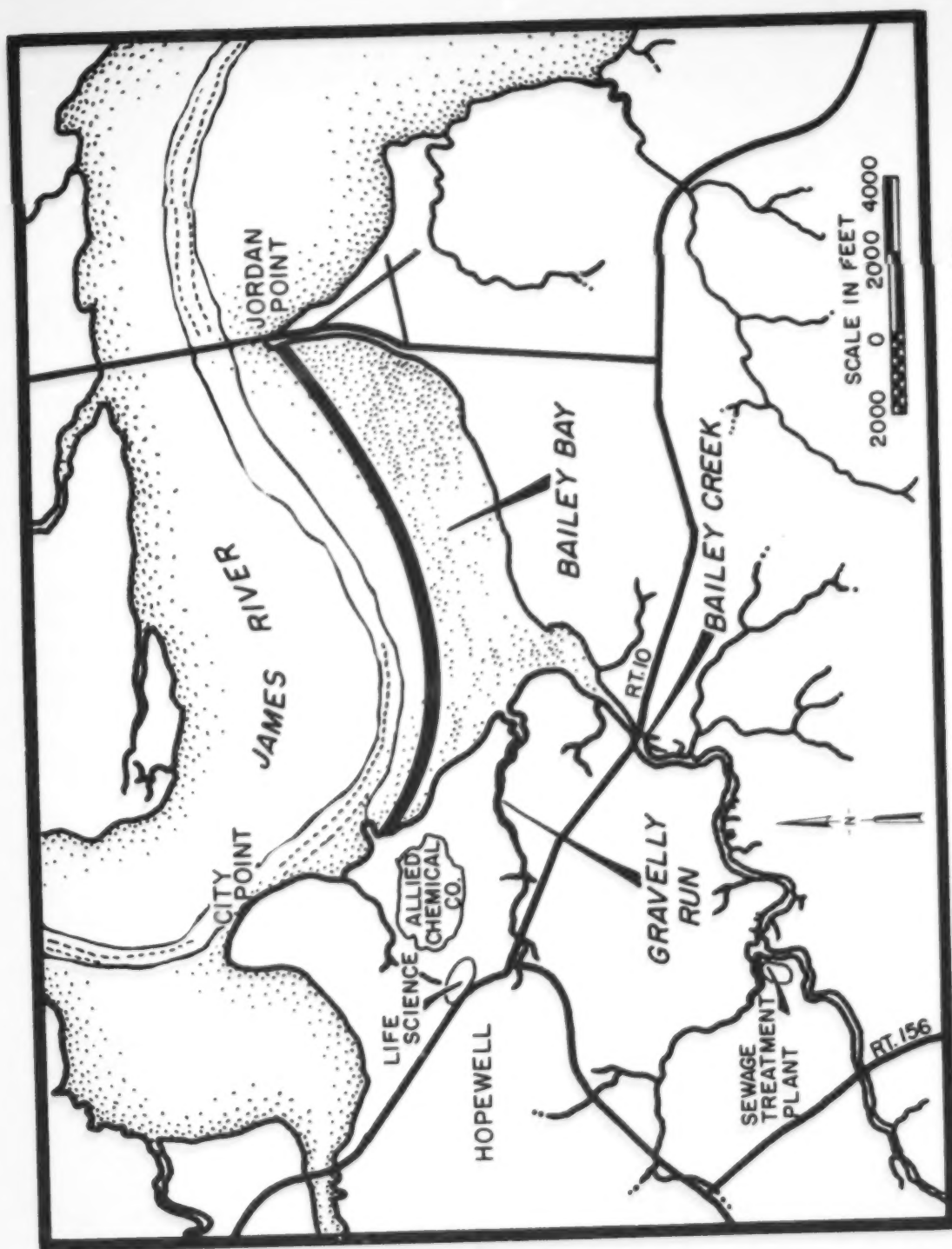


Figure 8. Engineering plan for damming Bailey Bay to contain Kepone.

- (4) Construct a 10-foot high MSL levee 1 mile east of City Point to Jordan Point and use area behind levee for spoil disposal from dredging maintenance or from other sources of contaminated material. The cost of this option is \$8 million, excluding elutriate treatment costs.
- (5) Construct a levee from Jordan Point to Bailey Creek and utilize area behind levee for disposal of dredged material from Bailey Creek and Gravelly Run. Seal area, cover with topsoil and seed with grass. Elutriate treatment, dredging, and construction costs have not been determined, but the levee would be 15 feet above MSL.

The Corps recommends using a dragline or bucket dredge for dredging operations because of their availability. However, cost estimates and the feasibility of using the Oozer dredge are being explored.

Three types of treatment, being investigated for the runoff and elutriate waters in all the above alternatives, are: conventional water purification with sand filtration, activated carbon, and ultraviolet/ozonolysis. Costs are presently being determined for the various projected flow rates.

The Corps' options for the Bailey Creek/Bailey Bay area may seem expensive. However, a prime objective of the project is to stop or control continuing inflows of Kepone from Hopewell. The Corps of Engineers is also investigating conventional mitigation measures to remove the Kepone located in the James River proper. The widespread distribution of the Kepone in the estuary may make it feasible to address only known "hot spots" with conventional removal methods.

NONCONVENTIONAL MITIGATION TECHNIQUES

Since there are high costs and inherent secondary pollution problems associated with the removal of contaminated sediments by dredging, Battelle Pacific Northwest Laboratories is examining nonconventional removal, neutralization, and isolation techniques. This phase of work focuses on evaluating alternatives to dredging, as well as treatment and/or fixation processes complementary to dredging for application to Kepone-contaminated sediments in the James River System. Three types of alternatives are being studied: (1) those which could be used to fix dredge spoils for disposal; (2) those which could be employed to treat elutriate or spoil slurries; and (3) those which could be applied in situ as substitutes to dredging.

Dredge spoil fixation techniques are designed to prevent further water or air pollution by using stabilizing agents capable of solidifying wastes and immobilizing contaminants. Candidate materials include asphalt, tar polyolefins, epoxy resins, silicates, and elemental sulfur. The desirability of any one fixation agent is based on the characteristics of the contaminant to be bound as well as the conditions of disposal which may lead to a breakdown of the structure of the fixed mass.

Each fixation agent being evaluated has been subjected to two types of standardized tests: (1) a short-term elutriate test; and (2) a longer term leach test. All fixation work was performed on a "standard" sediment prepared from a homogenized Bailey Bay sediment sample. The Kepone concentration in the samples was 1 µg/g. Only commercially available fixation agents were employed and an effort to include all companies currently marketing fixation processes was made. However, not all companies chose to participate and some companies have not yet submitted their final results.

The early results shown in Table 1 do not include all involved companies. Accordingly, the preliminary conclusions are not final and may not reflect the full potential of using fixation agents. To date, none of the samples exhibits any clear retardation of Kepone loss. In fact, several agents appear to enhance leachability. For the silicate agents increased leachability is believed to reflect the high pH associated with the fixation process. (Since Kepone is much more soluble under high pH conditions, the fixation process is actually releasing Kepone from sediments.) The gypsum system appears to physically break down when left standing in water. A preliminary evaluation of asphalt binders was made, but these could not be easily mixed with wet sediments unless heated. The mixing problems with asphalt binders may constitute excessive costs and equipment requirements for the volumes of sediments involved.

If dredging is employed to restore the James River System, there will be a need for the capability to treat elutriate, leachate, and/or the entire dredge spoil slurry to prevent subsequent escape and movement of low-level contamination. The applicability of various elutriate treatment approaches depends completely on the physical-chemical properties of the Kepone, as well as the nature of the liquid stream to be treated. For the purposes of the work conducted, candidate approaches were divided between biochemical and physical-chemical mechanisms.

A review of the literature indicated no evidence of microbial degradation of Kepone. However, as previously mentioned, Dr. Colwell indicated she may have identified some Kepone-degrading bacteria. Dr. Ralph Valentine of Atlantic Research, Alexandria, Virginia, identified six strains of fungi and molds which yielded 13-40 percent degradation of Kepone over a two-to three-week period. Best results were obtained when no additional carbon source was available to the organism.

A wide range of alternatives exists for the physical-chemical destruction of Kepone. Approaches being investigated are the use of oxidizing chemicals and processes utilizing electromagnetic waves of various frequencies.

Regarding the latter category, no data were found with respect to the effect of sunlight on Kepone degradation. Work with Mirex showed that it was not subject to photolysis to a large extent unless it was placed in an aliphatic amine solution. The decomposition product appeared to be a mixture of monohydride derivatives of Kepone.

To test the applicability of photolysis to Kepone, 10 mg/l in solutions of 100 and 10 percent amine were exposed to a sunlamp for one hour (Table 2).

TABLE 1. KEPONE CONCENTRATIONS IN LEACHATE SOLUTIONS ($\mu\text{g/l}$)

Fixation Type (a)	Leach Period in Hours					
	1	4	24	168	336	672
Company A - Silicate 1	1.04	0.99	1.01	1.81	1.74	2.09
Silicate 2	1.34	2.64	0.90	1.30	1.18	0.78
Silicate 3	1.33	1.88	1.31	1.42	1.04	1.02
Silicate 4	0.39	0.54	1.00	1.18	1.27	1.41
Company B - Silicate 1	0.07	0.06	0.074	0.166	0.158	0.10
Silicate 2	0.05	0.05	0.111	0.157	0.306	0.27
Company C - Gypsum	0.52	0.47	0.91	0.91		
Blank 1	<0.06	<0.06	0.076	0.058	0.050	0.22
Blank 2	0.117	0.04	0.104	0.081	0.11	

(a) Company names will not be identified until data are finalized and firms have been informed of their products' performance.

TABLE 2. EFFECTS OF SUNLAMP IRRADIATION IN AMINE SOLUTIONS

Solvent System	Strength of Solvent (%)	Kepone Concentration ($\mu\text{g/l}$)	
		1 Hour	23 Hours
Hexane	10	1,640	6,040
	100	3,700	530
Ethanolamine	10	2,230	7,970
	100	6,520	2,530
Triethylamine	10	54	18,620
	100	2,240	477
Ethylenediamine	10	1,715	117
	100	<23	

Tests with ethylenediamine show promise at higher concentrations. Work is currently underway to identify degradation products, assess the effectiveness of other secondary amines, and evaluate the concept for application to contaminated soils.

Gamma radiation can affect degradation, but required doses are considered too high. A residual of 0.14 $\mu\text{g/g}$ (88 percent removal) was obtained when sediment with 1.2 $\mu\text{g/g}$ Kepone was subjected to 144 megarad.

Work has also been performed on ozone-enhanced ultraviolet oxidation. Preliminary evaluations with a stock solution of 5.172 mg/l produced residuals of 20.9 $\mu\text{g/l}$ and 46.7 $\mu\text{g/l}$ over 1.5- and 2-hour exposures, respectively. Because of the need for the UV to penetrate any slurry being treated, a second set of tests is being performed with waters having a high particulate load.

Chemical oxidation tests conducted with chlorine dioxide and ozone showed that neither oxidant was effective in degrading Kepone. A second set of evaluations using chlorine dioxide and sunlight is now underway. Work is also underway at Envirogenics to determine the effectiveness of their catalytic reduction process for dechlorination, but data are not available at this time.

In situ processes as a category are the newest of the approaches to removal/mitigation of in-place toxic materials. As such, they are typically not as fully developed as other approaches, but may offer benefits as yet unmeasured. Several of the more promising options were selected for testing in the laboratory.

Preliminary findings indicate that biological approaches hold little promise for use in areas where Kepone contamination is of concern. The six strains of fungi and mold identified by Atlantic Research appear to be subject to dominance by natural bacteria in sediments. Therefore, application in situ may be hampered by poor growth if not loss of viability.

Although Kepone accumulation by biological systems followed by subsequent harvesting has been suggested, preliminary findings indicate that Kepone removal from the water in Bailey Bay by algae or vegetation would be slight due to the low amounts of dissolved Kepone in the water. (The partition coefficient between water and sediment for Bailey Bay was found to be 10^{-4}).

To gain information on rooted plant uptake from the sediments, barley uptake was studied in the laboratory. Battelle found that barley did not translocate Kepone to the stem and leafy parts. The Kepone attachment mechanism to roots is likely to be direct adsorption rather than biological uptake. This work with barley does not preclude rooted plant uptake possibility by other plants but, to date, no evidence supports rooted plant uptake.

Artificial means of accumulation may be more promising. Natural sorbents such as activated carbon and synthetic sorbents such as the macroreticular resins have been shown to be effective in concentrating organics similar to Kepone. In preliminary laboratory investigations, several commercial agents were found to have a partition coefficient 100 times that for Bailey Bay sedi-

ments. It was further determined that with the incorporation of magnetite into the structure of the sorbent beads, these particles could be spread through an area of contaminated sediments and be selectively retrieved after a period of accumulation.

Preliminary laboratory results for the first time period are presented in Table 3. The 863 and XAD-2 sorbents appear quite effective. They also display continued effectiveness beyond the initial two-week period. There is some concern, however, that such a process will be kinetically limited. The sorbent can quickly remove dissolved Kepone from interstitial waters, but this is only a minute portion of the total quantity in the system. Subsequent removal requires desorption and migration to the Sorbent. To study the nature of such movement, vertical columns of contaminated sediment were designed and a sorbent layer placed on the surface. After eight weeks, 0.5-inch segments were sectioned and analyzed independently to determine the depth of influence. Results are presented in Table 4. Sorbent 863 appears to have been effective at least to a depth of 3.5 inches. Additional analysis at increasing depths is presently underway to determine the ultimate depth of influence.

Physical retardation of Kepone to the water column through the use of an impermeable covering barrier or an in situ stabilization technique was also investigated. The use of a 2-mil sheet of polyethylene in the Bailey Bay area may be applicable, but venting to relieve pressure from anaerobic generation of gases may reduce effectiveness. The effectiveness of silicate-based agents for in situ stabilization is still under study.

In summary, no fixation agents have been found satisfactory to date, but several still need to be fully evaluated. Apparent problems with the more common silicate-based agents stem from Kepone desorption at the higher pH levels. At least three candidate elutriate/slurry processes have shown promise to date: UV ozonolysis; biodegradation with selected fungi and molds; and amine-assisted photolysis. Retrievable synthetic sorbent and polymer films both appear applicable as in situ approaches at this time. None of the elutriate treatment processes evaluated has shown potential for use in situ. The investigation results of the nonconventional mitigation techniques are summarized in Table 5.

Again, it must be emphasized that the information presented to date is preliminary and that many analytical data are yet to be evaluated and numerous tests must still be completed. Final recommendations will be made only after these have been concluded and viewed collectively.

Allied Chemical, in separate studies, indicated at the Kepone Seminar on September 20 and 21 that there were promising results obtained in using anthracite coal to immobilize Kepone through in situ selective sorption (2). They also reported the destruction of some Kepone residues through the use of caustic solutions at elevated temperature and pressure. Further efforts to coordinate these investigations with our study are underway.

TABLE 3. EFFECTIVENESS OF SORBENTS IN ACCUMULATING
KEPONE FROM BAILEY BAY SEDIMENTS

	2 wk Exposure		4 wk Exposure	
	Conc. in Sediment After 2 wk, $\mu\text{g/l}$	Apparent Removal, %	Conc. in Sediment, $\mu\text{g/l}$	Apparent Removal, %
XADZ(a)	0.80	49	0.53	66
XAD4(a)	1.18	24	1.06	32
863(b)	0.89	43	0.72	54
FILTRASORB(c)				
300	1.21	22	1.06	32
Magnetic Carbon	1.56	0	1.23	21
Blank	1.56	0	1.56	

- (a) Product of Rohm and Haas
 (b) Product of Diamond Shamrock
 (c) Product of Calgon

TABLE 4. EFFECT OF SURFACE APPLICATION OF SORBENTS WITH DEPTH

Depth, in.	Blank Kepone Content, $\mu\text{g/g}$	Sor bent 863(a)		XAD-4(b)	
		Kepone Content, $\mu\text{g/g}$	Apparent % Removal	Kepone Content, $\mu\text{g/g}$	Apparent % Removal
0.5		0.079	70	0.291	--
1.0	0.262	0.060	77	0.209	20
1.5		0.066	75	0.119	55
2.0	0.211	0.328	--	0.155	41
2.5		0.045	79	0.053	75
3.0		0.299	--	0.174	34
3.5		0.040	81	0.233	--
4.0				0.058	73

- (a) Product of Diamond Shamrock
 (b) Product of Rohm and Haas

TABLE 5. SUMMARY OF PRELIMINARY RESULTS AND STATUS OF NONCONVENTIONAL CANDIDATE ALTERNATIVE EVALUATIONS

Approach	Option	Results	Status
Fixation	Silicate Bases	High pH characteristics produce expensive leachate concentrations	Some agents still to be tested
	Gypsum Bases	Breakdown in water, ineffective	Rejected
	Epoxy Bases	----	Tests not complete
	Sulfur Bases	----	Tests not complete
Electrolyte Slurry Treatment	Asphalt	Too difficult to apply to wet sediments	Rejected
	Amine Photolysis	Some degradation rated with specific amines	Testing degradation products and applicability
	γ Radiation	Effective at excessive doses	Rejected
	UV-Ozonolysis	Effective on clear solutions	Testing in natural waters
	Ozone	Ineffective	Rejected
	Chlorine Dioxide	Ineffective	Testing in presence of
	Catalytic Reduction	----	Data not yet available
	Biological Degradation	Promising strains of fungi and mold identified	Deserves further consideration
	Biological	No significant degradation, bioaccumulation bad, harvesting too slow from sediments	Rejected
	Retrievable synthetic sorbents	Specific media highly effective	Tests are continuing
In situ	Polymer films	Feasible	Assessing probable effectiveness, long-term implications

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HUDSON RIVER - PCB STUDY DESCRIPTION AND DETAILED WORK PLAN

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INTRODUCTION

On September 8, 1976 the New York State Department of Environmental Conservation and the General Electric Company signed an agreement bringing to a close the action brought against General Electric relating to the discharge of polychlorinated biphenyls (PCBs) into the Hudson River. This paper presents a detailed description of the Department of Environmental Conservation's program for implementing Section 3 of the settlement which is the portion related to monitoring and reclamation of the river.

BACKGROUND

Polychlorinated biphenyls (PCBs) were first manufactured in 1929 and their chemical properties were soon discovered to be ideal for a number of industrial uses. They are extremely stable chemically and biologically, conduct electricity very poorly, and possess a very low solubility in water. In the United States, they have been used for a wide variety of purposes, most heavily as a heat transfer fluid and insulator in heavy electrical equipment. But, these same chemical properties create a significant biological hazard.

This hazard might have gone unnoticed had it not been for an industrial accident in Japan that has come to be called the Yusho ("rice oil disease") incident. In 1968 this disease (manifest primarily as a serious skin disorder) was traced to PCB contamination of rice oil during its manufacture. Since that incident, more research has turned up rather frightening facts.

Yusho victims are still exhibiting symptoms of the poisoning and even though not exposed to additional PCBs, they still have high levels of PCBs in their blood and other body tissues. Several deaths among the victims have been associated with malignant cancers, though it is not possible to conclusively state that the PCBs caused the cancers. Recent evidence shows that the rice oil and tissues of Yusho patients also contained polychlorinated dibenzofurans (PCDFs). PCDFs are more toxic than PCBs. It is therefore not possible to conclusively associate the symptoms of this incident with PCB poisoning^{1,2}.

Experiments with laboratory animals, including monkeys, however, confirm that many of the symptoms associated with Yusho are directly related to consumption of PCBs and persist in the bodies of all experimental animals long after they are removed from diets containing PCBs. In addition to deaths being noted at high doses, liver tumors have also been induced in mice and rats. An exhaustive summary of these effects can be found in the recent Criteria Document for PCBs (1976) published by the Environmental Protection Agency¹ and a report published by the United States Department of Health, Education and Welfare².

As a result of accumulating research on PCB toxicity, the United States Food and Drug Administration (FDA) has set standards for allowable levels of PCBs in various foods³.

THE PCB SETTLEMENT

Polychlorinated biphenyls were discovered to be a problem in the Hudson River in 1975. The United States Environmental Protection Agency and Fish and Wildlife Service analyzed samples of fish taken from the river and found that PCB concentrations were higher than the FDA limits by a substantial margin. The fish could thus not legally be shipped for interstate sale. Acting on this and additional evidence that the Department of Environmental Conservation (DEC) had itself collected, charges were brought against the General Electric Company (GE) for polluting the river with the toxic substance PCB. Administrative proceedings began on September 8, 1975. On February 9, 1976, after weeks of testimony and a substantial record of several thousand pages of transcripts, prefiled testimony, reports, studies and other exhibits, the Hearing Officer, Professor Abraham D. Sofaer, found that DEC had presented overwhelming evidence of GE's responsibility for high concentrations of PCBs in the upper Hudson's waters, sediment, organisms and fish. In a 77-page interim opinion, Professor Sofaer detailed the evidence and the violations⁴. It is interesting to note that he found that the unlawful actions were the consequence of both corporate abuse and regulatory failure by the responsible Federal and State agencies.

In order to determine the appropriate remedial measures, a second phase of the hearing was held during the spring and summer of 1976. As a result of this hearing, a settlement agreeable to all parties was negotiated and finalized exactly one year after the administrative proceedings began, September 8, 1976⁵.

The settlement calls for a comprehensive program of at least \$7 million to deal with PCBs in the Hudson River and related environmental concerns. General Electric was required to reduce its PCB discharges, which had been averaging about 30 pounds per day until 1972, to one pound per day beginning September 8, 1976, and to construct a wastewater treatment facility at the Hudson Falls and Fort Edward Capacitor Manufacturing Facilities. Total PCB discharges from the plants were reduced to one gram (0.022 pounds) per day by May 1977.

The agreement stipulated that GE was to cease using PCBs by July, 1977 and to perform \$1 million of research on several items including the environmental compatability of any substitute. Finally, GE was required to contribute \$3 million to the Department as its share of additional work to further monitor the presence and levels of PCBs; to investigate the need for remedial action concerning PCBs present in the Hudson and to implement such action, if necessary; and to aid in developing a program to regulate the storage and discharge of substances hazardous to the environment. New York State was, by the agreement, obligated to provide an additional \$3 million for this work and the Commissioner of Environmental Conservation became responsible for overseeing and expediting the required work. An overview of the provisions of the settlement related to studies of the Hudson River and the Department's activity to date in implementing them is shown in Table 1.

ADVISORY COMMITTEE

A key provision of the settlement is an Advisory Committee consisting of independent experts and governmental and private interests which was established to "review and make public recommendations to the Commissioner concerning the scope, content, progress and results of the programs, studies and expenditures."

The PCB Settlement Advisory Committee has been appointed and meets monthly to carefully evaluate the work in progress and make recommendations regarding results and further studies.

The relationship of this Advisory Committee to the Department and implementation of the settlement is given in Figure 1.

THE HUDSON RIVER PROBLEM

In order to better understand the Hudson River PCB problem, it is useful to know something about the river itself.

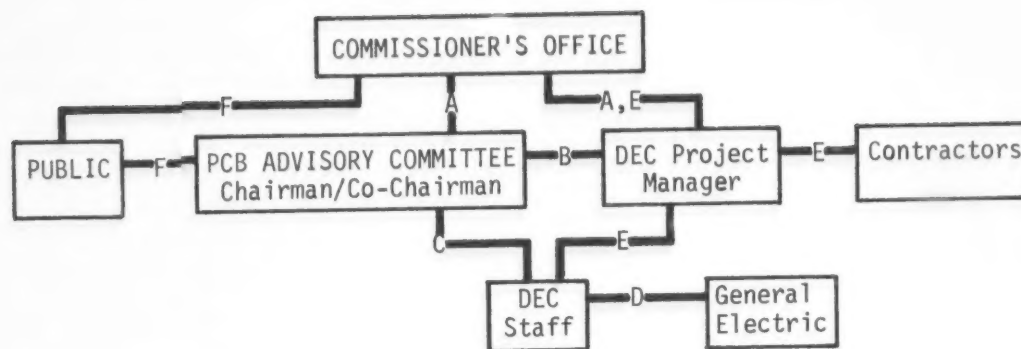
For most purposes, the Hudson River Drainage Basin can be divided into three sub-basins - the Upper Hudson River, the Mohawk River and the Lower Hudson River as shown in Figure 2.

Table 2 shows the relative area and water flows for these three basins. From Ft. Edward to Cohoes the Upper Hudson River is actually a series of low level dams and serves as part of the Champlain Canal (Figures 3 and 4). The Mohawk River serves as the eastern portion of the New York State Barge Canal and joins the Hudson River just above the Troy Dam.

The lower Hudson Basin is tidal over its entire 150 miles (241 km). Average tides are 4.4 feet (1.4 m) at the Battery, 3.0 feet (1 m) at Beacon and 4.8 feet (1.5 m) at Troy. Tidal flows at Poughkeepsie have been measured as 230,000 to 280,000 cfs (6,516-7,932 cms). Dye studies have shown that the flow actually oscillates with the tide, with a very slow net outflow. Because of this tidal flow, salt-water intrusion extends quite a distance upriver.

TABLE 1. OVERVIEW OF TASK REQUIRED BY SECTION 3 OF PCB SETTLEMENT

Settlement Provisions	Department Activity to Date
<u>I. Advisory Committee</u>	
The Commissioner of Environmental Conservation will establish an Advisory Committee consisting of independent experts, governmental and private interests which will, at regular meetings review and make public recommendations to the Commissioner concerning the scope, content, progress and results of the program, studies and expenditures for which provision is made in the agreement.	An Advisory Committee has been formed and it meets regularly.
<u>II. Other Funds</u>	
In the event that the funds herein provided for implementing remedial actions concerning PCBs present in the Hudson River shall be inadequate to assure protection of public health and resources, then the Department will use its best efforts to obtain additional funds from sources other than GE, that are necessary to assure such protection.	No action can be taken until a decision as to the need for and cost of specific remedial action is made.
<u>III. Overall River Program</u>	
1. Monitor the presence and levels of PCBs which have been discharged in Hudson River waters in water, sediment and biota.	A monitoring program has been developed by the Dept. and approved by the Advisory Committee. This program includes contracts for PCB mapping with Normandeau Assoc., PCB lab analysis with O'Brien and Gere, and water and sediment transport measurements with USGS. An extensive program of fish, macroinvertebrate, water and air monitoring by the Dept. is also underway.
	EPA special core study of estuary section was carried out in December 1976. Lamont-Doherty Lab will carry out studies to follow-up the results of this survey.
	For more detail see Table 3.
2. Further investigate the need for remedial action concerning PCBs present in the Hudson River.	Contracts for studies relating to taking no remedial actions and to removal of PCB contaminated sediments by dredging are underway (see Figure 5).
	The Advisory Committee has approved maintenance dredging by DOT of a small section of the east channel of the river near Ft. Edward. An Environmental assessment for this project has been prepared ^{6, 7} and approved. Dredging is expected to take place during the summer of 1977. Experience from this project will be useful in evaluating and design of future projects.
	No action can be taken until above studies are received.
3. Implement remedial action if necessary to protect public health and resources, concerning PCBs present in the Hudson River.	No action can be taken until a remedial action program is decided upon and implemented; however, an overall Hudson River research program is being prepared by the Advisory Committee.
4. Aid in developing a program to regulate the storage and discharge of substances hazardous to the environment if sufficient monies are available after implementing remedial action concerning PCBs.	
<u>IV. Work to be Carried out by GE (\$1 million)</u>	
GE will conduct research itself or by contract on the environmental compatibility of its substitute non-PCB dielectric capacitor fluids (\$400,000).	A substantial amount of work on the substitute has been done by GE. A preliminary report ⁸ on the substitutes has been published and is under review.
GE will conduct research to be approved prior to being undertaken by the Commissioner after his consultation with the Advisory Committee on the removal or treatment of PCBs in supernatant liquids and sediments from the Hudson River sludge (400,000).	The work study plan ⁹ presented by GE has been approved by the Commissioner on the recommendation of the Advisory Committee and work is underway.
GE will conduct research as specified by the Commissioner of the effects on the environment of not more than three substances which may be hazardous to the environment and which are to be selected by the Commissioner after his consultation with the Advisory Committee (\$200,000).	The Advisory Committee has been asked to recommend three substances for study. They have established a subcommittee for this task.



- | | |
|---|-----------------------------------|
| A. Give advice and respond to questions. | C. Technical resource. |
| B. Managerial direction. | D. Exchange of information. |
| 1. Advise DEC about short-term and long-term planning. | E. Managerial direction. |
| 2. Receive and react to periodic reports from DEC staff. | F. Public assess and information. |
| 3. Assist DEC in evaluations. | |
| 4. Assist DEC in preparing reports and recommendations to the Commissioner. | |

Figure 1. Organizational chart for the PCB settlement between General Electric and The Department of Environmental Conservation.

TABLE 2. HUDSON RIVER DRAINAGE BASIN AREA AND AVERAGE FLOW

Location	Area		Average Flow	
	mi ²	km ²	ft ³ /sec	m ³ /sec
Upper Hudson Basin Waterford	4,634	12,002	7,660	217
Mohawk River Basin Cohoes	3,456	8,951	5,630	159
Lower Hudson Basin Tributaries	5,300	13,727	7,100	201
Total Hudson Basin	13,390	34,680	20,390	577

From U. S. Department of Interior, Geological Survey, Water Resources Data for New York Water Year 1975, 1976.

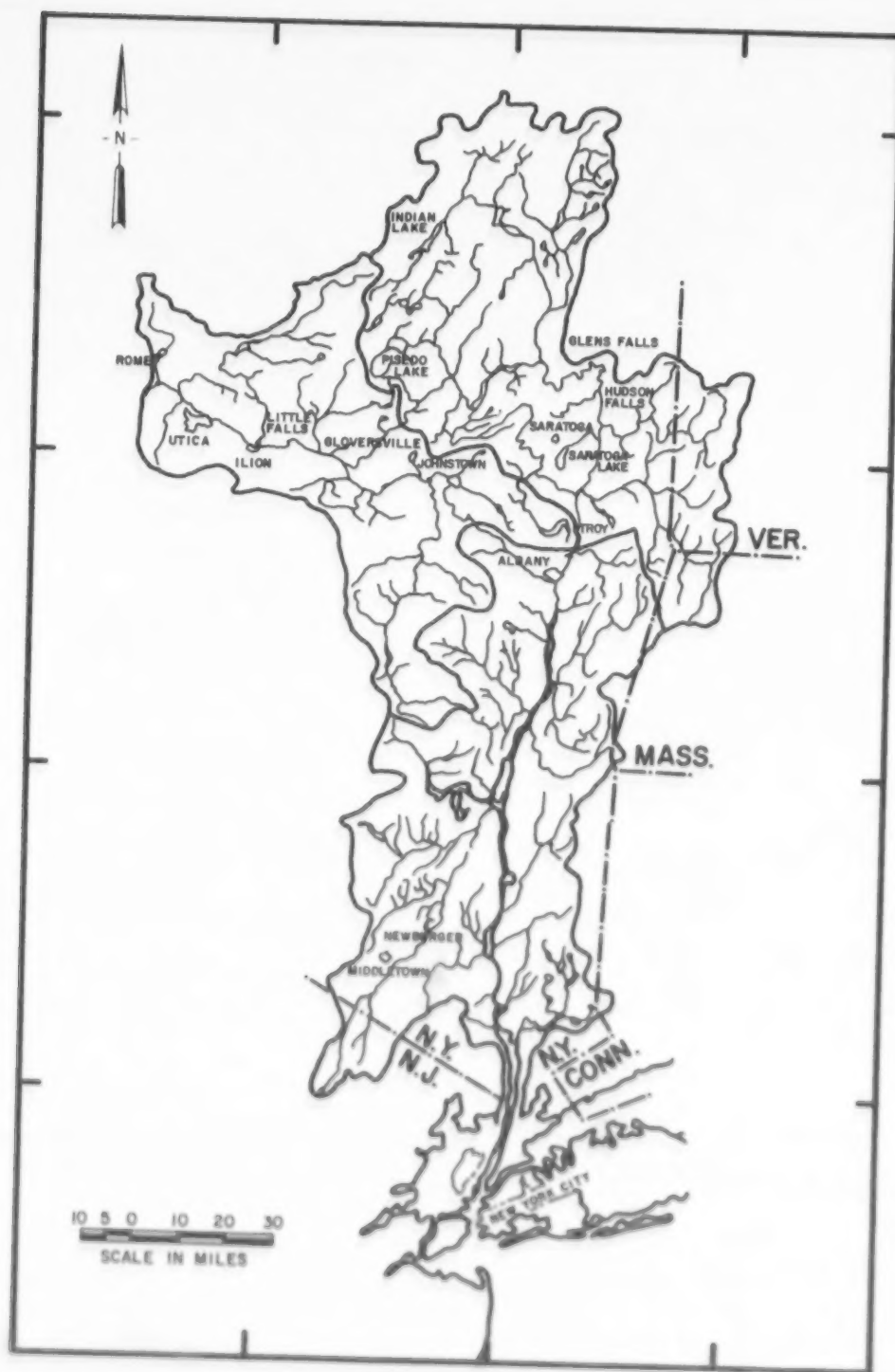


Figure 2. Hudson River Basin.

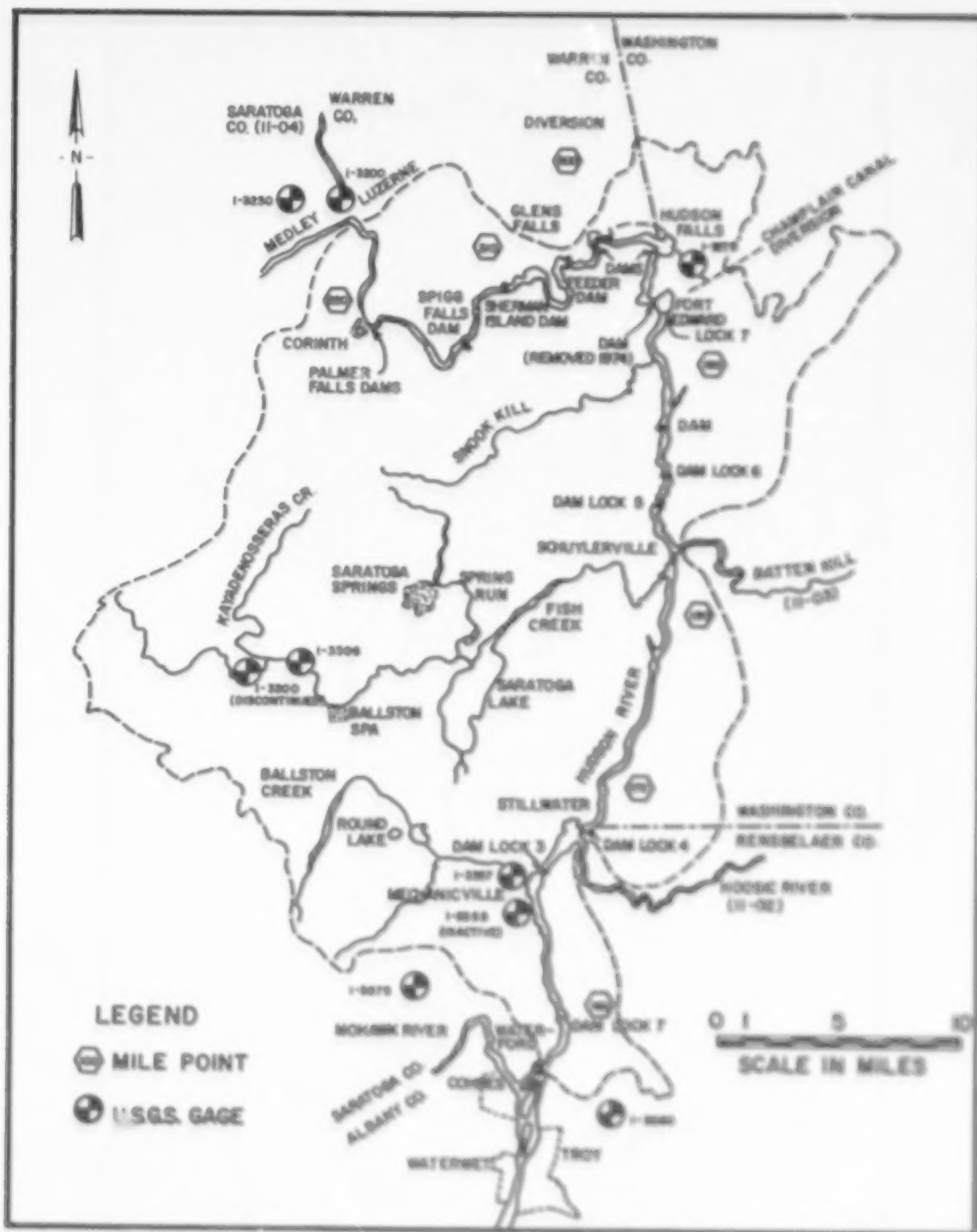


Figure 3. Upper Hudson River Basin.

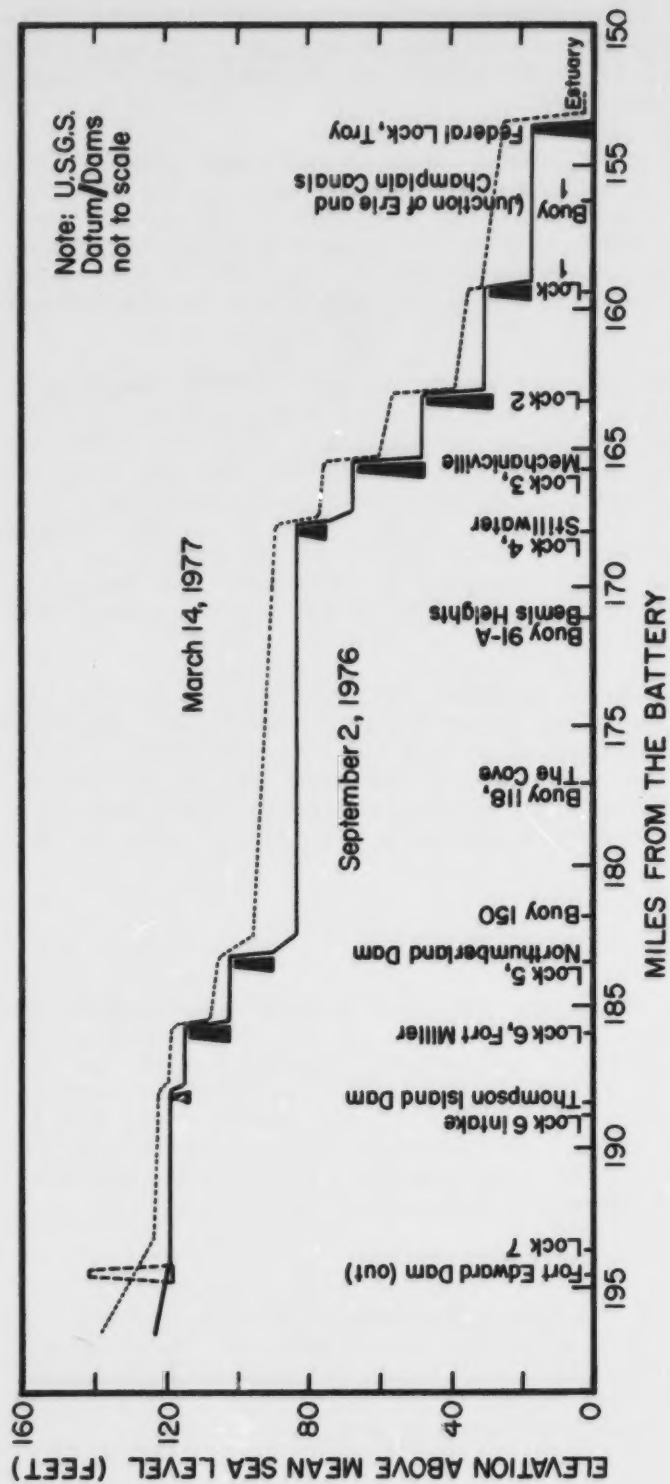


Figure 4. Upper Hudson River water surface profile.
Fort Edward to Federal Lock.

The 50 mg/l (0.05 o/oo) salinity fluctuates from 20 mi. (32.2 km) above the Battery (near Tappan Zee Bridge) to 70 mi. (112.7 km) inland (south of Poughkeepsie) depending on the freshwater flow.

Testimony given at the hearing clearly demonstrates that although the levels of PCBs in fish and other animals are alarming, most of the PCBs are held in the sediments on the river bottom and suspended in the water. Very little PCBs can be found in the water itself, but because of bioaccumulation, it is enough to create a serious hazard. "Clean" fish placed in this water in cages ("live-cars") have accumulated dangerous PCB levels in their flesh within one month⁴.

Existing data indicate that the sediments in the section immediately below the GE discharges at Fort Edward are the most contaminated. General Electric discharged large volumes of PCBs for at least 25 years. Much of this probably accumulated in the sediments impounded behind the dams south of the manufacturing plants. The first dam was located in Fort Edward, but, for various reasons, it was removed in the late summer of 1973¹⁰. Some of the contaminated sediment which subsequently moved downriver has been removed by Department of Transportation's (DOT) dredging to maintain the Champlain Canal. Much, however, still remains, particularly in the region between Fort Edward and the Thompson Island dam.

The essence of the Hudson River problem is that these PCBs are now slowly leaching back into the river and if no action is taken, may continue contaminating the river and its biological system far into the future. It is also possible, however, that the contaminated sediments may be covered or moved by nature to a section of the river where they may no longer present a problem or that they may have so spread out over the entire length of the river that no action is possible.

THE PLAN OF STUDY

Although research prior to and since the court proceedings demonstrates a serious problem does exist with respect to PCBs in the Hudson River, the complete scope of the problem and the appropriate remedial action are not clear. The State plan adopted is a complex program to ascertain the seriousness and precise location of PCB contamination in the Hudson River and to evaluate the cost, environmental as well as financial, of any remedial action. This program has been formulated by DEC, approved by the Advisory Committee, and is now underway (Figure 5). A summary of this plan follows.

MONITORING STUDY

In order to define the concentrations and movements of PCBs in the river system, a comprehensive monitoring program has been developed. The program¹¹ outlined in Table 3 includes monitoring of fish, macro-invertebrates, sediment, hydrology, wastewater treatment plant input, water and air. Some highlights of this program are described in the following paragraphs.

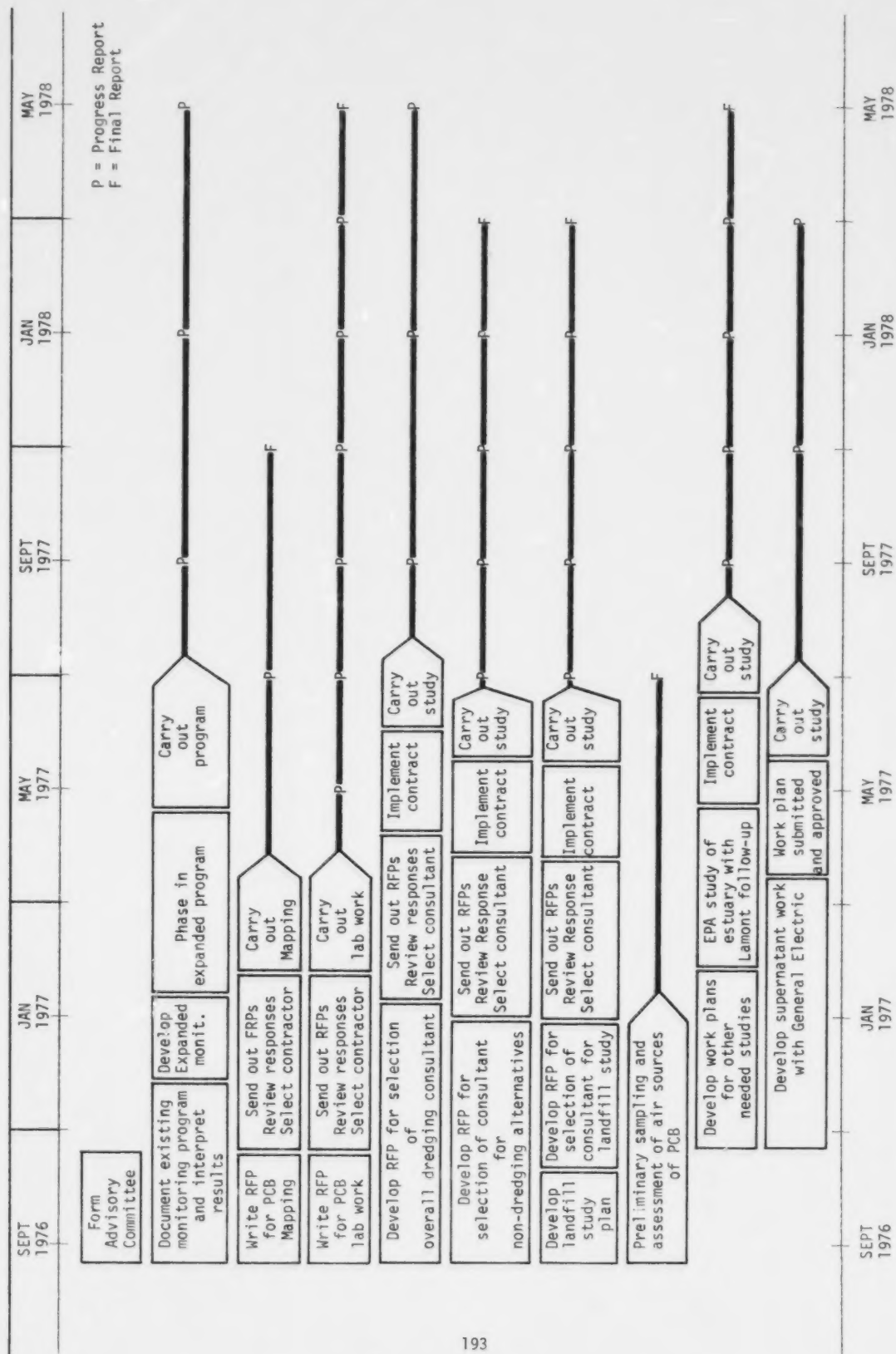


TABLE 3. PCB-HUDSON RIVER MONITORING PROGRAM

Element	Description of Program	Being Carried Out By
Hydrology	Several additional gaging stations have been established in the Upper Hudson River.	USGS
Sediment	An extensive number of bed sediment core and grab samples are being taken in the Upper River to map the PCB contaminated areas. Some cores are being analyzed for radioactive Cesium-137 in order to date them.	Collections by Normandeau Assoc.; PCB analysis by O'Brien and Gere; Cesium-137 analyses by USGS
	Several suspended sediment stations have been established to monitor movement of sediments and their PCB content.	USGS
Groundwater	A special study of bed-load sediment transport of PCBs is underway.	Rensselaer Polytechnic Inst.
	A screening survey of PCB concentrations in the Lower Hudson River has been completed.	EPA.
	A detailed follow-up study of the estuary sediments and their PCB concentrations is underway.	Lamont Doherty Geological Lab.
	Limited groundwater samples are being taken as part of the study of landfills and dredge disposal sites and as part of a water supply program.	Roy F. Weston Assoc; DEC Div. of Pure Waters; Dept. of Health
Water Column	Water column data will be collected regularly in the Upper Hudson River. Municipal water supplies using Hudson River water are being monitored regularly.	USGS; DEC Division of Pure Waters; DOH

(continued)

TABLE 3 (continued).

Element	Description of Program	Being Carried Out By
Fish	Fish will be collected at six sampling locations spread throughout the river from Stillwater to the Tappan Zee Bridge. Most of the sampling will take place in the Lower Hudson River where commercial fishing interests are the greatest.	Collection by DEC Division of Fish and Wildlife; analysis by O'Brien and Gere.
Macro-invertebrates	Macroinvertebrate samples will be collected at selected stations throughout the spring and summer.	Collected by DEC Div. of Pure Waters and Dept of Health; analyses by O'Brien and Gere.
Wastewater	A screening program of sewage treatment plant sludges is planned to determine which if any are potentially contributing significant quantities of PCBs to the river	Samples collected by DEC Div. of Pure Waters; analyzed by O'Brien and Gere.
Air	A sampling network of air quality has been set up in the Fort Edward area.	Samples collected by DEC Div. of Air Resources and analyzed by DOH.

The Department's Division of Fish and Wildlife is responsible for a basic biological monitoring program, and as part of this program, it will be collecting fish at six sampling locations spread throughout the river from Stillwater to the Tappan Zee Bridge. Most of the sampling will take place in the Lower Hudson River where commercial fishing interests are the greatest. Nine common species are expected to be sampled, mostly during May and June, but American Shad were taken during their spawning run in April. In addition to these studies, macroinvertebrates are being sampled throughout the spring and summer.

These animals, as well as all other materials, will be analyzed for PCBs by chemists at O'Brien and Gere Engineers of Syracuse, New York. This firm follows a rigorous quality control program designed and monitored by the Department of Health and can handle the large number of samples expected during the program. Before the study is complete, several thousand samples will be analyzed for PCBs using a gas chromatograph-electron capture detection.

Normandeau Associates, Inc. of Bedford, New Hampshire, was awarded a contract to map the river bottom measuring the sediment thickness and PCB content from Fort Edward to the Troy dam, in the region where sediment was shown to be most heavily contaminated.

In December 1976, the EPA Region II office used a helicopter to collect Hudson River sediments between Troy and the Tappan Zee Bridge because sampling in this region had previously been scanty. Results of this survey¹² suggested that the Lower Hudson River also has highly contaminated sediment in at least four of the twenty sites sampled. To further investigate this possible problem, a contract is in process with Lamont Doherty Geological Laboratory. Lamont Laboratory has collected, analyzed and archived cores in the Lower Hudson over the past several years. With this unique collection and new ones from selected sites, it should be possible to get a much better understanding of PCB levels throughout the estuary portion of the Hudson River.

The United States Geological Survey is cooperating in the study by continuing their work on sediment transport, particularly during big storms and the spring thaw. Because high water in the river often moves large volumes of sediment, PCB measurements provide an indication of whether, and how rapidly, contaminated sediments in the Upper Hudson move downriver.

Not included as part of the program, but a study that will contribute to it, is an aquatic ecology and water quality study being done by Equitable Environmental Health, Inc. for Niagara Mohawk Power Corp.¹³ as input to their preparation of an environmental impact statement for possible reconstruction of a hydraulic dam at Fort Edward.

NEED FOR ACTIVE RESTORATION

All of this new information, and the previously collected data, will be synthesized and analyzed by three different teams of scientists and engineers. Two of these teams have been commissioned to study the fate of PCBs in the river if no action is taken to remove them. The first, the firm of Lawler, Matusky and Skelly of Tappan, New York, will concentrate on PCB contaminants

in the sediments and their movement in the river. The second, Hydrosience Associates, Inc. of Westwood, New Jersey, will concentrate its efforts on the biological systems and PCB uptake from the water and sediments.

The third team is Malcolm Pirnie, Inc. from White Plains, New York, who has been awarded a contract to determine the technical feasibility, engineering methodology, cost and environmental impact of dredging contaminated sediments from the river. Although many other methods have been suggested for removing PCBs from the river, at the present moment, dredging is the only proven technology which could be applied in the immediate future. Other techniques would probably take at least five years before they could be used on the necessary scale. By then, the highly contaminated, and presumably confined, sediments might well be elsewhere.

Additional information on dredging of PCB contaminated sediments will be gained as a result of dredging operations planned for the summer of 1977⁶ 7. Although the primary purpose of this operation is maintenance of the canal system in the Fort Edward area, the work will be closely monitored in order to evaluate the practicality of dredging in PCB contaminated areas.

Dovetailing with Malcolm Pirnie's work, Weston Environmental Consultants of West Chester, Pennsylvania, are evaluating various landfills and dredge material disposal sites. If dredging is to be seriously considered, the dredged materials must be treated and/or placed somewhere. Leaching could return much of the PCBs back to the river unless adequate precautions are taken.

The results of these studies are due early in 1978. Hopefully, they will provide the basis for deciding whether remedial action is desirable. If dredging is the proper action to be taken, how, when and where should it be done to provide the greatest removal with the least environmental impact and least cost? If it appears that dredging is unwise, then what direction should DEC take in attempting to solve this problem? The answers to these questions will not be simple but the work being carried out as part of the PCB settlement will insure that in making them we will have the best scientific input possible.

A multitude of geologists, chemists, biologists and engineers from State and Federal agencies, private firms and educational institutions are directly involved in this massive study. A list of the principal groups involved is given in Table 3. Such a cooperative endeavor, although difficult, is becoming more commonplace as we realize the necessity of integrating our scientific and technological knowledge to solve problems of our own making. This study can be viewed as a test to see if such an effort can succeed.

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AN OVERVIEW OF BOTTOM SEDIMENT PROBLEMS IN SAGINAW
RIVER AND BAY, MARINETTE-MENOMINEE HARBOR, AND
WAUKEGAN HARBOR

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ABSTRACT

Three waterways in the Great Lakes were selected for an overview of their current toxicant problems in bottom sediments. The Marinette-Menominee Harbor has severe arsenic problems associated with leaching from an adjacent waste storage area. Polychlorinated biphenyl contamination of bottom sediments is common to both Saginaw River and Bay and Waukegan Harbor. Problems related to fish contamination, proper dredging techniques and disposal of bottom sediments are discussed.

INTRODUCTION

Each year an average of 10 million cubic meters of bottom sediments are dredged from lakes and connecting channels of the Great Lakes. Approximately ninety percent of this volume is dredged to maintain, improve or extend navigable waterways and harbors. The remaining ten percent of this volume as gravel or sand is used as aggregate supplies to the construction industry.

During the past five years, attention has been drawn to persistent toxic chemicals, particularly in channels and harbors of the Great Lakes that are maintained by dredging. As a consequence, the U. S. Environmental Protection Agency and the U. S. Army Corps of Engineers are concurrently involved in evaluation of toxicants in bottom sediments, the persistence of such toxicants, the interaction with biota, and the most environmentally sound method of dredging and ultimate disposal of contaminated bottom sediments.

A number of channel and harbor areas in the Great Lakes have been evaluated prior to maintenance dredging. Toxic contaminant problems were evaluated in three waterways of particular importance to the Great Lakes basin-Marinette-Menominee Harbor, Saginaw River and Bay, and Waukegan Harbor.

SAGINAW RIVER AND BAY

The Saginaw River is formed by the union the Tittabawassee and Schiawassee Rivers in the State of Michigan. The Saginaw River flows north into the southwest end of Saginaw Bay of Lake Huron.

Early in 1972 polychlorinated biphenyls were reported at high levels (1). PCBs were detected at 5.3 mg/kg in the suspended solids fraction of Saginaw River water and at 353 mg/kg in wastewater treatment sludge from the Bay City Wastewater Treatment Plant (2). PCB levels were attributed to a number of point source discharges on the Saginaw River and its tributaries. Through abatement activities of the pollution control agency in the State of Michigan (Michigan Water Resource Commission) PCB discharge to the Saginaw drainage basin was significantly reduced.

The presence of PCBs in the Saginaw River and Bay resulted in contamination of fish populations. The Michigan Department of Agriculture detected PCB levels in channel catfish in excess of the U. S. Food and Drug Administration tolerance level of 5 mg/kg. As a result, a ban was issued for commercial catfishing in the inner Saginaw Bay area (3). The continued detection of PCBs in Saginaw Bay fish indicated that PCBs previously released to sediments continue to be detected in resident fish populations.

In view of existing PCB problems in Saginaw River and Bay, the U. S. Environmental Protection Agency was unable to concur with proposed maintenance dredging and disposal in 1976 until a complete sediment analyses program for PCBs was undertaken.

The U. S. Environmental Protection Agency (Chicago Office) and the U. S. Army Corps of Engineers (Detroit District) conducted an intensive survey of Saginaw River and Bay in October, 1976. PCBs were sampled at 35 locations in Saginaw River and at 11 locations in Saginaw Bay. PCB concentrations in bottom sediments ranged from 0.1 to 22.9 mg/kg for all locations. Samples taken in the downstream vicinity of the City of Saginaw Wastewater Treatment Plant ranged from 5.5 to 22.9 mg/kg PCB. PCB concentrations near the Bay City Waste Water Treatment Plant ranged from 3.5 to 11.8 mg/kg. Sediment samples obtained in Saginaw Bay had considerably lower PCB concentrations ranging from 1.3 to 4.2 mg/kg.

Although point sources of PCB discharge have been curtailed along the Saginaw River, significant concentrations of this chemical remain in the bottom sediments. A diked disposal facility is near completion in the Saginaw Bay area and will be used for disposal of these sediments during maintenance and dredging operations.

MARINETTE - MENOMINEE HARBOR

The Marinette-Menominee Harbor is located on Lake Michigan in the Green Bay vicinity between the States of Michigan and Wisconsin. The harbor consists of an approach channel, an inner harbor and a turning basin.

In 1973 the U. S. Environmental Protection Agency brought to the attention of the Ansul Company the potential hazard of a waste storage area adjacent to the Marinette-Menominee Harbor. The uncovered waste storage area held 45,000 tons of waste salt containing 1,350,000 lbs. of organic arsenic and approximately 600,000 lbs. of elemental arsenic. Because a satisfactory solution for disposal could not be obtained, Ansul Company reconditioned storage facilities for the waste salt on a temporary basis.

In November, 1975, the Great Lakes Surveillance Branch of the U. S. Environmental Protection Agency obtained sediment samples from 10 locations in Marinette-Menominee Harbor (Figure 1). Sediments at locations 2, 6, and 7 were primarily silt. Sediments at other locations were primarily sand and gravel (Tables 1, 2).

Bulk sediment analysis indicate a severe arsenic contamination problem (Table 3). Extremely high arsenic levels were detected in the turning basin at location 2 in the vicinity of the Ansul Company. Arsenic contaminated sediments were found in all samples downstream of the turning basin. Higher concentrations were detected along the southern side of the navigation channel.

In addition to arsenic contamination, sediments at location 2 showed increased concentration of oil and grease, lead, and manganese. These concentrations were moderate at other locations with the exception of a high iron level at location 1.

Macroinvertebrate data and field observations show low numbers and little diversity of organisms at five locations (Table 4). The absence of macroinvertebrates at locations 2 and 7 indicate toxic conditions resulting from elevated arsenic levels.

Because of high arsenic levels in sediment, the apparent toxicity to benthos downstream of the turning basin, and the bioaccumulation effects of arsenic in freshwater biota, sediments downstream of location 1 were classified as unsuitable for open lake or bay disposal.

During 1977, the Ansul Company received a permit to dispose of the waste salt in a chemical landfill in Illinois. Disposal of these waste salts is currently underway.

WAUKEGAN HARBOR

Waukegan Harbor is located on the northwest coastline of Illinois on Lake Michigan. The harbor is a federal navigation channel and performs an additional function for significant small boat traffic.

In January, 1976, the Illinois Environmental Protection Agency notified the U. S. Environmental Protection Agency that high concentrations of polychlorinated biphenyls had been detected in the discharge of a local industry which discharges to Waukegan Harbor. The discharge from the facility had contributed over 100,000 pounds during a 20 year period to the harbor. The

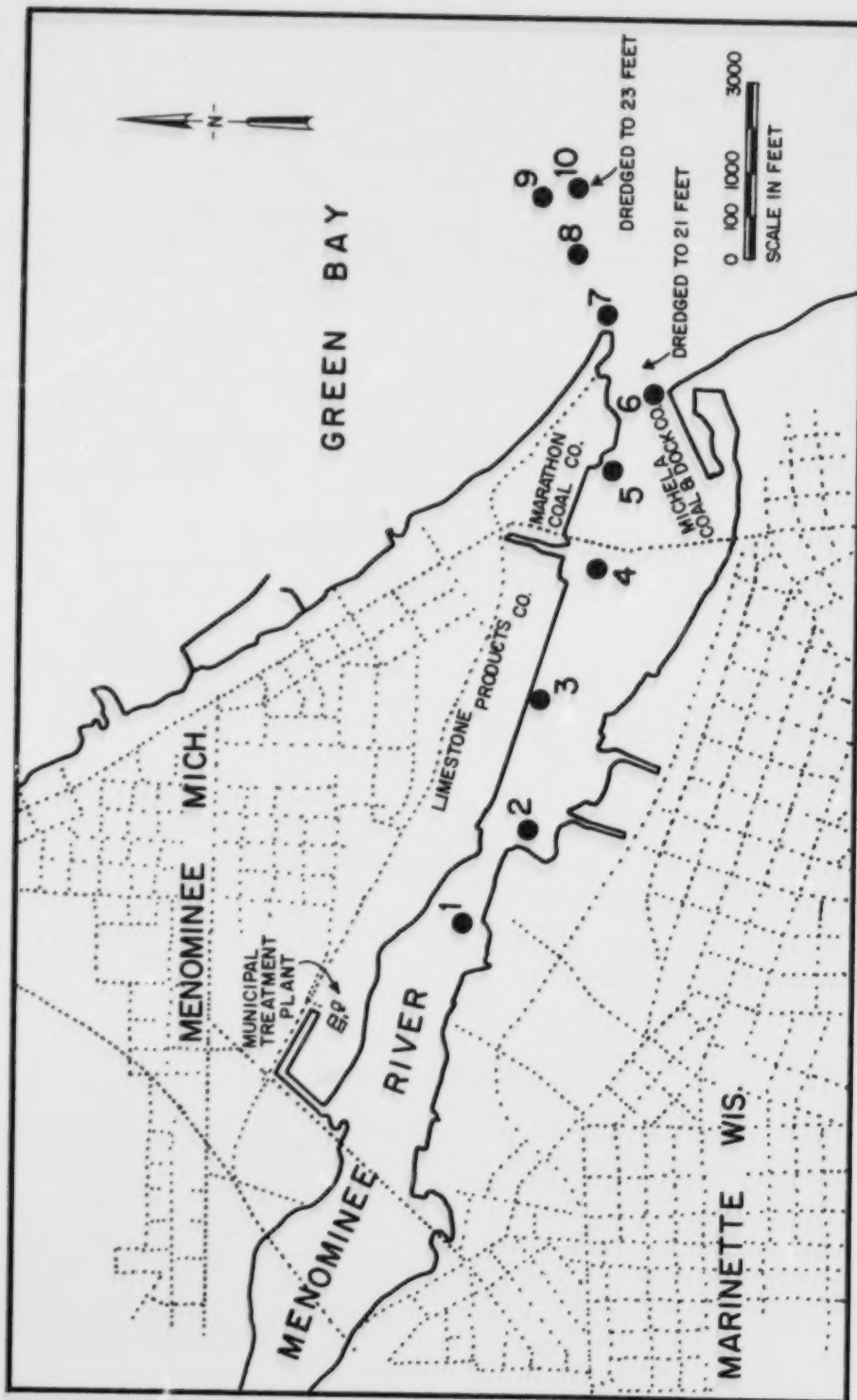


TABLE 1. FIELD OBSERVATIONS AT MARINETTE-MENOMINEE HARBOR

HARBOR: Marinette - Menominee, Wisconsin and Michigan

SAMPLED: November 5, 1975

Station No.	Depth (ft.)	Observations				General Remarks
		Color	Sample Description	Odor	Oil	
MAR 75-1	14	Dark brown	Sand, gravel	None	None	Bark chips no organisms
MAR 75-2	26	Dark brown	Silt	Earthy	Trace	Wood fibers few organisms
MAR 75-3	27	Dark brown	Fine sand, gravel	Slight earthy	Trace	Woodchips, coal detritus
MAR 75-4	26	Brown	Silty sand	None	Trace	Woodchips, detritus no organisms
MAR 75-5 replicate	23 23	Brown Brown	Sand, medium Sand, medium	None None	Trace Trace	Detritus, few worms Detritus, few worms
MAR 75-6	28	Dark brown	Sandy silt	Slight	Trace	Wood fibers, detritus few organisms - 1 bug
MAR 75-7	27	Dark brown	Fine sand	Slight	None	Few worms
MAR 75-8	27	Brown	Fine sand, some silt	None	None	No organisms
MAR 75-9	24	Light brown	Medium sand	None	None	No organisms
MAR 75-10	31	Brown	Fine sand	None	None	No organisms some detritus

TABLE 2. SIEVE ANALYSIS AT MARINETTE-MENOMINEE HARBOR

HARBOR: Marinette - Menominee, Wisconsin and Michigan

SAMPLED: November 5, 1975

Sieve No. and Description	Sediment Size Analysis by Percent at Each Station				
	MAR 75-1	MAR 75-2	MAR 75-3	MAR 75-4	MAR 75-5
Retained on #10 Medium Gravel and Larger	10	9	23	12	6
Retained on #20 Fine Gravel	8	3	5	3	6
Retained on #60 Medium and Coarse Sand	57	8	55	62	46
Retained on #200 Fine Sand	11	8	9	10	13
Passing #200 Silts and Clays	14	72	8	13	29

(continued)

TABLE 2 (continued).

HARBOR: Marinette - Menominee, Wisconsin and Michigan

SAMPLED: November 5, 1975

		Sediment Size Analysis by Percent at Each Station							
Sieve No. and Description	MAR 75-5 split	MAR 75-5 replicate	MAR 75-5 replicate split	MAR 75-6	MAR 75-7	MAR 75-8	MAR 75-9	MAR 75-10	
Retained on #10 Medium Gravel and Larger	6	10	11	5	8	4	4	4	
Retained on #20 Fine Gravel	8	5	8	2	6	3	7	2	
Retained on #60 Medium and Coarse Sand	56	71	66	20	12	33	74	73	
Retained on #200 Fine Sand	8	13	12	10	23	19	4	7	
Passing #200 Silts and Clays	22	1	3	63	51	41	11	14	

TABLE 3. BULK SEDIMENT ANALYSES AT MARINETTE-MENOMINEE HARBOR

HARBOR: Marinette - Menominee, Wisconsin and Michigan

SAMPLED: November 5, 1975

Parameter	MAR 75-1	MAR 75-2	MAR 75-3	MAR 75-4	MAR 75-5	MAR 75-5 split	MAR 75-5 replicate	MAR 75-5 replicate- split
Total Solids %	75.3	32.0	73.2	67.4	69.4	69.6	69.7	73.7
Volatile Solids %	<1.00	14.4	1.95	1.91	2.64	2.06	2.73	2.10
Chem. Oxy Demand	11,000	200,000	12,000	21,000	20,000	21,000	20,000	32,000
T. Kjehl Nitrogen	310	5,400	330	620	360	470	540	1,100
Oil-Grease	<250	3,100	300	500	<250	<250	400	300
Mercury	<0.1	0.2	0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Lead	<10	74	<10	35	<10	<10	13	14
Zinc	25	190	34	40	30	30	30	26
T. Phosphorus	150	1,200	180	210	190	170	190	240
Ammonia Nitrogen	20	390	18	33	23	23	21	30
Manganese	180	880	220	300	220	200	170	160
Nickel	<8	26	<8	<8	<8	<8	<8	<8
Arsenic	<2	87	3	10	5	5	5	5
Cadmium	<2	9	<2	<2	<2	<2	<2	<2
Chromium	6	31	6	8	7	7	6	7
Magnesium	5,200	18,500	6,900	7,500	6,600	4,900	3,700	3,800
Copper	6	50	9	13	7	7	7	6
Iron	61,000	17,000	5,900	6,200	6,200	7,300	6,500	7,000

All values mg/kg dry weight unless otherwise noted.

(continued)

TABLE 3 (continued).

HARBOR: Marinette - Menominee, Wisconsin and Michigan

SAMPLES: November 5, 1975

Parameter	MAR 75-6	MAR 75-7	MAR 75-8	MAR 75-9	MAR 75-10
Total Solids %	53.4	58.9	62.9	74.1	71.2
Volatile Solids %	12.1	3.60	3.10	<1.00	1.04
Chem. Oxy. Demand	83,000	51,000	36,000	3,500	4,900
T. Kjell. Nitrogen	1,800	1,000	890	66	130
Oil-Grease	900	500	400	<250	<250
Mercury	<0.1	<0.1	<0.1	<0.1	<0.1
Lead	24	22	20	<10	<10
Zinc	67	52	44	17	23
T. Phosphorus	420	310	280	150	150
Ammonia Nitrogen	100	53	46	<10	24
Manganese	380	330	310	130	150
Nickel	12	12	12	<8	<8
Arsenic	14	7	6	3	3
Cadmium	<2	<2	<2	<2	<2
Chromium	11	9	6	6	4
Magnesium	10,800	13,900	16,300	2,500	7,100
Copper	19	14	9	3	8
Iron	9,200	7,700	6,900	5,700	3,700

All values mg/kg dry weight unless otherwise noted.

TABLE 4. MACROINVERTEBRATE ANALYSIS FROM MARINETTE-MENOMINEE HARBOR

HARBOR: Marinette - Menominee, Wisconsin and Michigan

SAMPLED: November 5, 1975

Taxa	Number of Organisms for Each Taxa			
	MAR 75-1	MAR 75-2	MAR 75-4	MAR 75-6
				MAR 75-7
Diptera				
<i>Chironomus</i> sp.			7	1
<i>Dubiraphia</i> sp.			1	
<i>Dicerotendipes</i> sp.			11	
<i>Procladius</i> sp.		1	10	3
Oligochaeta				
<i>Limnodrilus</i> sp.			5	6
<i>Tubifex</i> sp.				2
Ephemeroptera				
<i>Hexagenia limbata</i>				1
Isopoda				
<i>Ascellus</i> sp.				2
Amphipoda				
<i>Gammarus fasciatus</i>	1		1	4
				1
Total No. of organisms	1	1	35	25
Total No. of taxa	1	1	6	7
				8
				3

U. S. Environmental Protection Agency requested that the U. S. Army Corps of Engineers suspend all dredging plans for the harbor until levels of PCBs in the channel sediments could be determined.

In May, 1976, the Great Lakes Surveillance Branch of the U. S. Environmental Protection Agency obtained seven sediment samples within the federal navigation channel. Eight additional samples were collected with the harbor area (Figure 2).

Total PCB concentrations ranged from 0.1 mg/kg near the opening of the harbor to 4200 mg/kg at the north end of the harbor (Table 5, Figure 2). Sediments near the source of past discharges in the north section of the harbor are heavily contaminated. Field observations of these sediments indicated they were gray-black in color with a strong petroleum odor. Sediments near the opening to the harbor consisted of fine to medium sand. Material in this vicinity consists of littoral drift sands which move north to south along the shore.

It was recommended that sediments lakeward of the South Pier are suitable for open lake disposal. Sediments within the harbor upstream of this location require confined disposal. Sediments at the north end of the inner basin will require special dredging operations when removed to reduce turbidity and overflow to minimize contact between water and severely contaminated sediments.

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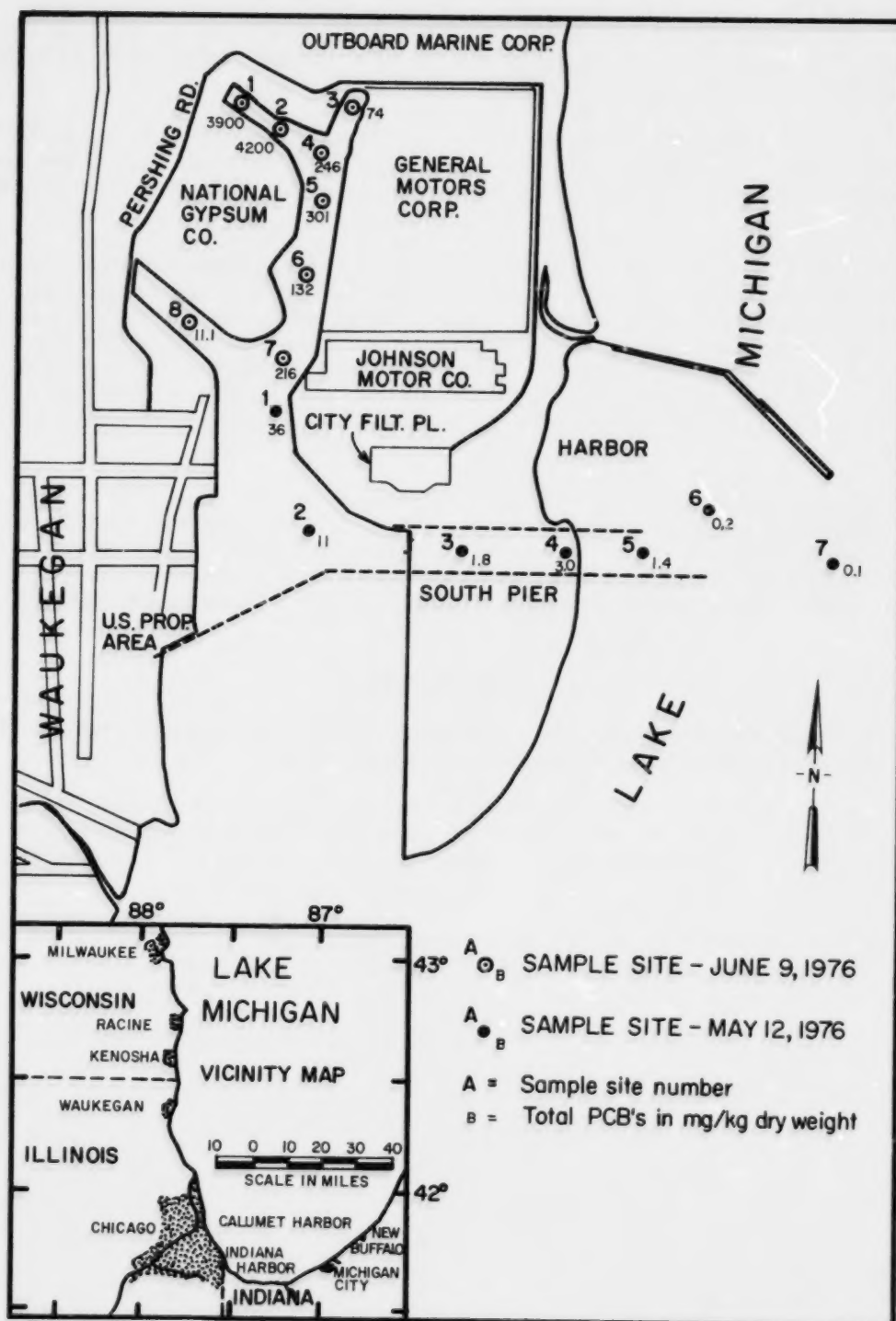


Figure 2. Sampling stations at Waukegan Harbor.

TABLE 5. POLYCHLORINATED BIPHENYL CONCENTRATIONS AT WAUKEGAN HARBOR

HARBOR: Waukegan, Illinois

SAMPLED: May 12, 1976

Station Number	Percent Moisture	Aroclors			Total PCB
		1242	1248	1016	
1	50.5	16	20		36
2	50.4	6.7	5.8		12.5
2 split	54.1	5.4	5.9		11.3
2 replicate	57.3	5.2	5.4		10.6
2 replicate/split	53.3	4.9	6.0		10.9
3	24.0	0.7	1.1		1.8
4	32.1	NF	3.7		3.7
4 split	33.2	0.6	2.4		3.0
4 replicate	25.5	0.5	1.3		1.8
4 replicate/split	28.4	1.0	1.3		2.3
5	21.4	0.3	1.1		1.4
6	17.9	NF	0.2		0.2
7	16.8	NF	0.1		0.1

All values in mg/kg (ppm) dry weight.

(continued)

TABLE 5 (continued).

HARBOR: Waukegan, Illinois

SAMPLED: June 9, 1976

Station Number	Percent Moisture	Aroclors			Total PCB
		1242	1248	1016	
1	19.9		2600	1300	3900
2	31.1		1200	3000	4200
3	33.9		32	42	74
4	56.3		68	180	248
5	50.7		61	240	301
6	48.6		73	59	132
7	55.4		120	98	218
8	35.0		8.3	2.8	11.1

All values in mg/kg (ppm) dry weight.

NF: None found. This indicates that the PCB level was below the detection limit of 0.1 mg/kg.

IMPACTS ASSOCIATED WITH THE DISCHARGE OF DREDGED MATERIAL INTO OPEN WATER

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ABSTRACT

With few exceptions, impacts of aquatic disposal are mainly associated with the physical effects. These possible effects are persistent, often irreversible, and compounding. Geochemically, releases are limited to nutrients with negligible release of toxic metals and hydrocarbons. Biochemical interactions are infrequent with no clear trends and elevated uptake of toxic metals and hydrocarbons are negligible to nonexistent.

INTRODUCTION

Navigable waterways of the United States have, through the years, played a vital role in the nation's economic growth. The Corps of Engineers (CE), in fulfilling its mission to maintain, improve, and extend these waterways, is responsible for the dredging and disposal of large volumes of sediment each year. Dredging is a process by which sediments are removed from the bottom of streams, rivers, lakes, and coastal waters; transported via ship, barge, or pipeline; and discharged to land or water. Annual quantities of dredged material currently average about 300,000,000 cubic yards (186,000,000 dry tons) in maintenance dredging operations and about 80,000,000 cubic yards (48,000,000 dry tons) in new work dredging operations with the total annual cost now exceeding \$150,000,000 (1).

In recent years, as sediments in many waterways and harbors have become contaminated, concern has developed that dredging and disposal of this material may adversely affect water quality or aquatic organisms. A number of localized studies have been made to investigate the environmental impact of specific disposal practices and to explore alternative disposal methods. However, these studies have not provided sufficient definitive information on the environmental impact of current disposal practices, nor have they fully investigated alternative disposal methods. As a result, the CE was authorized by Congress in the 1970 River and Harbor Act to initiate a comprehensive nationwide study

to provide more definitive information on the environmental impact of dredging and dredged material disposal operations and to develop new or improved dredged material disposal practices. The U. S. Army Engineer Waterways Experiment Station (WES) was assigned the responsibility of developing and managing a comprehensive multidisciplinary five-year multimillion dollar research program known as the Dredged Material Research Program (DMRP). A more detailed planning, technical and management structure can be found in references 2 and 3.

The DMRP is subdivided into four projects. The Environmental Impacts and Criteria Development Project (EICDP) will be discussed in this paper. The EICDP is further divided into six general task areas that are generally described by their respective titles. These tasks are: 1A - Aquatic Disposal Field Investigations; 1B - Movements of Dredged Material; 1C - Effects of Dredging and Disposal on Water Quality; 1D - Effects of Dredging and Disposal on Aquatic Organisms; 2D - Confined Disposal Area Effluent and Leachate Control; and 1E - Pollution Status of Dredged Material.

Task 1A includes major field investigations where field application of laboratory findings of the numerous biological, chemical, and physical investigations of open water disposal are underway. This task involves hopper dredged and barge disposal in freshwater, estuarine, and marine locations. Pipeline discharge investigations are being conducted as a part of Task 1B and 1E.

The development of mathematical models to predict dispersion and final fate of dredged material comprise the general objectives of Task 1B.

Tasks 1C and 1D are involved with determining the effects of open-water disposal on water quality and aquatic organisms through laboratory investigations. Specifically, Task 1C is concerned with the mobilization and immobilization of chemical constituents during open-water disposal and longer term release after the material has settled to the bottom. Task 1D is concerned with the biological uptake and utilization of chemical constituents and the longer term physical and chemical effects of aquatic organisms through laboratory evaluations.

Task 2D involves the characterization of contaminant mobility within and from upland dredged material containment areas and the effects on the surrounding ecosystem.

Task 1E involves the previous listed investigations and combines their results with additional investigations to develop more meaningful and implementable regulatory criteria.

Fundamental to understanding the impact of sediment discharge and resuspension on water quality is an understanding of how chemical constituents, which may have various effects on aquatic organisms, are associated with dredged sediments.

Sediments may be separated into several components or phases which are classified by their composition and mode of transport to the estuarine environment. Among them are detrital and authigenic phases.

Detrital components are those which have been transported to a particular area usually by water. Detrital materials are derived from soils of the surrounding watershed and can include (a) mineral grains and rock fragments (soil particles) as well as stable aggregates, (b) associated organic material, and (c) culturally contributed components derived from agricultural runoff and industrial and municipal waste discharges.

Authigenic components are those which are formed in place or have not undergone appreciable transport. These materials are generally the results of aquatic organisms and include (a) shell material (CaCO_3), (b) diatom frustules (SiO_2), (c) some organic compounds, and (d) products of anaerobic or aerobic transformations.

In considering the *in situ* association with various sediment phases of trace elements in estuarine sediments, the water contained in inter-particle voids or interstices must be considered. This is termed interstitial water (IW). In relation to the overlying water, chemical constituents may frequently be enriched in the IW by several mechanisms. Some constituents (metals and some nutrients) are ionically bound to the sediment in several exchange locations. These include the exchange sites of the silicate phase and exchange sites associated with organic matter or trace elements complexed with the organic phase. Heavy metals are also associated with hydrated manganese and iron oxides and hydroxides which are present in varying amounts in the sediment. Another location for heavy metals is in the sediment organic phase. The metals are incorporated into living terrestrial and aquatic organisms and are relatively stable but may be released into the sediment-water system during decomposition. The greatest concentration of chemical constituents, however, is contained in the silicate mineral fraction (earth's crustal material) of a sediment.

From the previous discussion of elemental partitioning and for analytical purposes, the following categories of sediment components will be considered.

a. Interstitial water (IW). This water, an integral part of sediment, is in dynamic equilibrium with the silicate and organic exchange phases of the sediment as well as with the easily decomposable organic phase.

b. Mineral exchange phase. That portion of the element that can be removed from the cation exchange sites of the sediment using a standard ion-exchange extractant (NH_4OAc , dilute HCl , NaCl , MgCl_2 , etc).

c. Reducible phase. This phase is composed of hydrous oxides of iron and manganese as well as hydroxides of Fe and Mn, which are relatively reducing (anaerobic) conditions. Of particular importance are the toxic metals (As, Cu, Cd, Ni, Co, and Hg) that may be associated with these discrete Fe or Mn phases as occlusions or coprecipitates.

d. Organic phase. This phase or partition of elements is that considered to be solubilized after destruction of the organic matter. This phase contains very tightly bound elements as well as those loosely chelated by organic molecules. An initial extraction by an organic chelate may be needed to differentiate between the loosely bound and tightly bound elements.

e. Residual phase. This phase contains primary minerals as well as secondary weathered minerals which are for the most part a very stable portion of the elemental constituents. Only an extremely harsh acid digestion or fusion will break down this phase. By far the largest concentration of metals is normally found in this fraction.

A particular element or molecule can be present (be partitioned) in a sediment in one or more of several locations. The possible locations include: (a) the lattice of crystalline minerals, (b) the interlayer position of phyllosilicate (clay) minerals, (c) adsorbed on mineral surfaces, (d) associated with hydrous iron and manganese oxides are hydroxides which can exist as surface coatings or discrete particles, (e) absorbed or adsorbed with organic matter which can exist as surface coatings or discrete particles, and (f) dissolved in the sediment interstitial water. These locations also represent a range in the degree by which an element may become dissolved in the receiving water. This range extends from stable components in the mineral lattices, which are essentially insoluble, to soluble compounds dissolved in the sediment interstitial water, which are readily mobile. Electrochemical (Eh, pH) changes after disturbing and resuspending anaerobic bottom sediments may result in possible solution or precipitation of many elemental species and should be thoroughly characterized.

A sediment characterization procedure to elucidate the phase distribution of contaminants in dredged material must be applicable to many types of marine and freshwater sediments, both aerobic and anaerobic. To be realistic, sediment disturbance must be minimal. Thus, drying, grinding, and contact with atmospheric oxygen is undesirable. Such a technique has been developed and subjected to preliminary evaluation (4). The sediment phases previously listed here are shown in their relative order of mobility and bioavailability, interstitial water being most mobile and consequently most available. When a contaminant enters a body of water it normally enters two or three fractions in varying concentrations but cannot be distinguished from natural levels by a bulk or total analysis. An example of the distribution of iron in a sediment from Mobile Bay, Alabama (5), has concentrations in the interstitial water (0.23% of total), exchangeable (2.13% of total), reducible (76.4% of total), organic (12.6% of total), and residual (8.55% of total). The total sediment iron concentration is 31,100 mg per kg of sediment. Iron is shown to be widely distributed throughout the sediment phases with the interstitial water containing the least, the exchangeable phase containing a small fraction, and the moderately reducible phase containing the largest concentration of iron in the sediment. Under aerobic conditions the iron would be immobile or fixed in the sediment. Copper distribution in this sediment is as follows: interstitial water (0.0032% of total), exchangeable (none detected), reducible (6.35% of total), organic (32.63% of total), and residual (61.2% of total). Total copper concentration is 37.8 mg per Kg sediment. This residual phase, which contains the largest fraction of sediment copper, can only come in the solution during geologic weathering processes and has no acute or chronic biological impact. The organic phase may go through various transformations and a fraction of the organic portion could be rendered mobile. However, movement would be slow and solution copper would be rapidly diluted to ambient levels. These results only hint at the complexity of chemical constituent distribution within

and among sediments; for a detailed discussion of sediment chemistry and water quality interrelations the reader is referred to references 5 and 6.

Results of the Task 1C, laboratory investigations of the impact of disposal of water quality, show that ammonium, manganese, iron and orthophosphate were released from anaerobic sediments during disposal and initial mixing and after the sediment has settled to the bottom (7, 8). It was found, however, that the sediments scavenged or cleaned the water column of numerous toxic heavy metals and nutrients when contaminated fine-grained harbor sediments were dispersed in a water column. No release of chlorinated hydrocarbons was detected (7, 9) during the simulated open-water disposal of dredged material from a broad selection of marine, freshwater, and estuarine sediments. After the sediments had settled and formed a new sediment-water interface, several constituent release and immobilization patterns were detected (7, 8, 9). Release from the sediments to the water column, with the exception of iron, manganese, and some nutrients, was extremely small. Several toxic heavy metals were released in concentrations less than one part per billion levels from either contaminated harbor sediments or noncontaminated sediments. It must be emphasized that these processes and transformations occur naturally in all sediments at similar levels (7, 8) and do not appear to be of a pollutional nature.

Further studies of chemical constituent release mechanisms (10) have evaluated conditions that enhance release of toxic metals when the sediment-water geochemical environment is drastically changed. As an example, the significant release of zinc to the water soluble phase was shown to occur at pH 5 under oxidizing (Eh) conditions. It must be emphasized that these acid-oxidizing, pH-Eh conditions do not normally occur in open-water disposal as anaerobic sediments normally remain near neutral pH and the oxidation processes that occur in the water column are not such as to result in an acidic condition (10). Subsequently, after the sediment settles it normally returns to an anaerobic and near neutral pH condition. On the other hand, if this sediment is placed in an upland containment area where oxidizing conditions can occur for a year or more and the sediments are high in total sulfide (common in many fine-grained estuarine sediments), the pH can become acidic and result in significant release of some contaminants (10) to the water soluble phase. Therefore, judicious selection of the disposal mode (open-water versus upland) and an understanding of the long-term implications of either disposal mode is very important. These previous observations and numerous other geochemical transformations of an extensive list of sediment constituents are discussed in detail in references 7, 8, 9, and 10.

The previously reported research has suggested little release of most chemical constituents from dredged material, further emphasizing the need for determining the biological effect of chemicals associated with the sediment solid fraction. The physical effect, irrespective of chemical nature of this fraction, on various organisms must also be thoroughly evaluated. Investigations underway in Task 1D are determining the effects of turbidity (suspended dredged material) on aquatic organisms, the uptake of sediment sorbed metals and pesticides, the ability of organisms to migrate vertically through deposits of dredged material, and the biological effects of sediment contained oil and grease.

Turbidity studies (11), conducted with marine, estuarine, and freshwater organisms have shown lethal concentrations of suspended dredged material to be significantly (an order of magnitude or more) higher than those concentrations observed in the field. In these laboratory studies the mortality of select organisms were demonstrated in concentrations of suspensions of dredged material exceeding 2-20 grams per liter (2,000 - 20,000 ppm) at 21-day exposure times. Field observations have shown turbidity or suspended particulate levels to be less than 1 gram per liter (1,000 ppm) for exposure times of only hours. Based on these and other observations, it was concluded that the physical effect of turbidity from dredged material discharge in open-water would have minimal biological impact. Consequently, the primary impact of turbidity is of an aesthetic nature and must be controlled and treated as such. The only exception to this would be the sensitive coral reefs of Florida and Hawaii where low concentrations of suspended particulate can significantly impact large areas. Additional studies are currently underway to evaluate the uptake of contaminants from the suspended dredged material by aquatic organisms (benthic and water column) and will be completed later this year.

Other physical impact investigations underway in Task 1D are evaluating the ability of estuarine and freshwater benthic organisms to recover vertically after being covered or smothered by various loadings of dredged material (12). These laboratory evaluations are being conducted by the University of Delaware, Lewes, Delaware, and have demonstrated that select organisms (clams, crabs, and benthic worms) have been able to recover through as much as a meter covering or have been smothered by as little as a few centimeters covering of different types of dredged material. The organisms generally recovered through the deposits in a matter of hours, and minutes in some cases. These studies are investigating combinations of sand dredged material deposited on mud and mud dredged material on sand substrates. The most drastic biological impact was noted when unlike materials were placed on each other. Especially where a sand dredged material was placed on a mud substrate and covered normally mud dwelling organisms that were not suited for mobility through the sand or where sand dwelling organisms were quickly smothered by a mud covering. Judicious selection of disposal site where sand is placed on a sand bottom or mud on a mud bottom is imperative to minimize immediate or long-term physical impact at the site. Field studies in this task demonstrated that benthic organism recolonization (13) of dredged material mounds formed during disposal was relatively rapid and the processes were attributed in some part to vertical migration. However, a significant number of organisms also may be brought out with the dredged material and affect recolonization patterns.

Toxic heavy metal uptake studies (14) are a significant part of Task 1D and involve biological assessment of estuarine and freshwater shrimp, clams, and benthic worms grown in contaminated sediments from the Houston Ship Channel, the Ashtabula River (Ohio), and other locations. The Houston Ship Channel sediments, highly contaminated with toxic heavy metals and chlorinated hydrocarbons, were generally toxic to a number of the organisms studied but were chosen a worst case material. This dredged material is not disposed in open-water but confined in a land containment area. The organisms that lived through the experiments, however, did not appear to take up any toxic heavy metals. They did, however, take up significant quantities of iron and manganese which

have very limited, if any, toxological properties. Zinc was the only other metal to show an accumulation trend. The uptake results could not be correlated to sediment bulk or total constituent concentrations. Freshwater studies with Ashtabula River sediments demonstrated that when freshwater worms from a clean environment were placed on the Ashtabula sediments, metals generally were taken up by these organisms. Uptake, however, reached concentrations exhibited in organisms that normally live in these sediments and did not exceed this level, and when the animals were transferred to clean sediments, they returned to their original or initial body burden. This study is nearing completion and will contribute significantly to the knowledge of metal uptake from contaminated sediments and its relation to aquatic disposal of dredged material. Pesticide uptake studies (15) have shown that maximum utilization by benthic organisms was from the interstitial water and minimum uptake from the solid sediment fraction. Perhaps, covering pesticide contaminated sediments with "clean" material at a disposal site will mitigate the organism utilization by isolating the contaminated material from the active benthic community that lives at or slightly below the sediment-water interface.

Task 1E investigations for the development of meaningful and implementable regulatory criteria for Public Laws 92-500 and 92-532 and other EICDP studies have shown conclusively that no relationship exists between "bulk" or "total sediment analysis" sediment characteristics and the effect of aquatic disposal on water quality or aquatic organisms (4, 5, 6, 7, 8, 9, 10, 15, 17, 18). These investigations have, however, shown that the "elutriate test" (19, 20) can be used to predict water quality perturbations and water column biological impacts (5, 6, 16, 17, 18). Further development and implementation of dredged material regulatory criteria have resulted in publication of "Interim Guidance" (20) for Section 404(b)1 of Public Law 92-500 pursuant to the 5 September 1977 Federal Register (21). This document, recently published and released by the WES, includes "cookbook" procedures and interpretive guidance for the Federal Register (21) and discusses procedures to be used for an ecological evaluation of the discharge of dredged and fill material in inland waters. The testing procedures include sediment analyses, water column evaluations, elutriate tests, water column bioassay, mixing zone estimations, and other physical and biological evaluations. Development of a benthic bioassay is currently a DMRP priority at WES, and under contract. It is envisioned that a benthic bioassay will be developed within the next twelve to twenty-four months. Field verification of the required regulatory procedures is underway at this time at numerous marine and freshwater locations (22) and will complement the completed laboratory research.

Large scale field investigations of the short- and long-term physical, chemical, and biological impacts of open-water disposal are completed in Long Island Sound, Lake Erie near Ashtabula, Ohio, the Gulf of Mexico near Galveston, Texas, Puget Sound off Seattle, Washington, and in the Pacific Ocean off the mouth of the Columbia River (23, 24). Chemical water-column effects duplicate the laboratory investigations previously reported in this paper, where only low levels of some nutrients and the metals iron and manganese were apparently released. Turbidity or suspended particulate was found in concentrations significantly (an order of magnitude or more) lower than concentrations shown to have an impact on a broad range of aquatic organisms (11) and persisted

only for a few hours. Significant impacts noted in these studies were the mounding of dredged material on the bottom of the dump sites. Biological recolonization studies of these mounds are incomplete at this time. However, there is initial evidence of rapid biological recolonization of some of the disposal areas. Sediment chemistry at the sites have shown elevated concentrations of chemical constituents in the sediment interstitial water at the disposal site as well as the control or reference areas. Movement or release of these chemical constituents out of the sediments of the disposal or reference sites was not apparent.

Studies are complete where organisms at select sites are being analyzed for metals or chlorinated hydrocarbon uptake. Initial evidence from the Eatons Neck disposal site in Long Island Sound, Ashtabula in Lake Erie, and in Puget Sound off the Duwamish Waterway has shown no increased uptake of numerous toxic and nontoxic heavy metals and chlorinated hydrocarbons by several organisms when compared with control or reference areas. These field studies were completed in December 1976 and the final results, conclusions and recommendations are in publication (24). Petroleum hydrocarbon uptake studies (25) have shown minimal uptake from highly contaminated sediments.

CONCLUSIONS

1. The field evaluations are verifying results demonstrated in the laboratory investigations.
2. Water column impact during disposal appears minimal to nonexistent and effect is predominately aesthetic in nature.
3. Leaching of toxic heavy metals from the disposal mound into the water column appears no greater than from natural sediments of similar geologic character. Chlorinated hydrocarbon release was not detected. Nutrients were released to small concentrations greater than background.
4. The major bottom impact found at disposal sites was the physical mounding of the material. Benthic recolonization of the mounds appears relatively rapid.
5. "Bulk" or total sediment analysis does not relate to any mobile or bio-available fraction of a sediment nor can it predict or evaluate water quality and ecological perturbations.
6. Water quality criteria and bioassays have been developed for Public Law 92-500 and 92-532 and are being field verified at this time.
7. Toxic heavy metal uptake studies are incomplete but initial trends suggest minimal to no impact in marine and estuarine sediments.
8. Petroleum and chlorinated hydrocarbon uptake studies are complete at this time, and initial trends suggest minimal uptake from solid phase of sediments.

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A BIOASSAY FOR THE TOXICITY OF SEDIMENT TO THE MARINE MACROBENTHOS

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ABSTRACT

A bioassay has been developed to determine the acute toxicity of the settleable phase of dredged material to the marine benthos. Five benthic invertebrates representing different taxonomic and trophic positions were allowed to acclimate to control (non-polluted) sediment and were then covered by a layer of either test or control sediment. Mean survival after ten days of exposure was significantly different from the controls for sediment from the Duwamish River, Wa; Houston Ship Channel, Tx; Bailey Creek, Va; and Raritan River, NJ; but there was no significant difference for sediment from Coos Bay and the Skipanon River, Or. There were substantial differences in survival among the five test species. The most sensitive species was the infaunal amphipod, Paraphoxus epistomus.

INTRODUCTION

The final Revision of Ocean Dumping Regulations and Criteria published by the Environmental Protection Agency¹ requires, under certain conditions, bioassays of the liquid, suspended, and solid phases of sediments proposed for dredging and disposal in the marine environment. Procedures for these bioassays were recently published by the Corps of Engineers². Results of experiments which contributed to the development of the bioassay for the solid or settleable phase of dredged material are presented in this report.

Our objective was to develop a test for the acute toxicity of the settleable components. The bioassay was designed not to be sensitive to burial or changes in sediment particle size distribution. Such effects can certainly disrupt benthic communities within dump site boundaries, but are unavoidable even during the disposal of unpolluted sediment. We were interested in measuring the toxicity of dredged solids whose disposal might result in the trophic or physical transport of pollutants beyond the dump site.

The bioassay technique roughly simulates the dumping of dredged material into the sea. Five macrobenthic invertebrates representing different taxon-

omic and trophic positions were selected as the test species because of the vulnerability of the benthos to the settleable portion of dredged sediments. These organisms were allowed to acclimate to control (non-polluted) sediment and were then covered in different replicates by a layer of either test or control sediment. Except during the one hour period of initial settling, the bioassay aquaria were supplied with a continuous flow of seawater which carried away the dissolved and suspended phases. Survival relative to controls after ten days of exposure was the primary response criterion.

Bioassays were conducted for sediments from the Atlantic, Gulf of Mexico, and Pacific coasts of the United States. The collection sites were chosen to provide a comparison of the toxicity of sediments which had been exposed to a variety of kinds and degrees of pollution.

MATERIALS AND METHODS

SEDIMENT SAMPLES

Benthic bioassays were performed on sediments from Yaquina Bay, Coos Bay (4 stations) and the Skipanon River, Oregon; the Duwamish River (3 stations), Elliott Bay, and Puget Sound, Washington; Houston Ship Channel, Texas (5 stations); Bailey Creek, Virginia; and the Raritan River, New Jersey (Table 1). There are no significant sources of pollution in the vicinity of the Yaquina Bay collection site. The four Coos Bay stations are in a channel next to a number of log loading docks. The Skipanon River station is adjacent to a fishing marina. Bailey Creek is near the site of the Kepone contaminations of the James River. The Duwamish, Raritan, and Houston Channel systems are exposed to a variety of industrial and domestic sources of pollution. Slip No. 1 in the Duwamish was the site of a PCB spill on 13 September 1974. The benthic bioassay sediment sample from slip No. 1 was collected after two attempts had been made to clean up the PCB contamination³. The Elliott Bay station is located at an experimental dump site for Duwamish River sediments⁴. Houston Channel stations II, III, IV, and V are near a chlor-alkali plant, pulp and paper mill, oil refinery, and sewage outfall, respectively. Station I is off Morgan's Point at the entrance to the channel.

The sediment samples were maintained at 4°C from the time of collection until the initiation of the bioassay, a period that did not exceed two weeks. The samples were either sieved through a 0.5 mm screen or frozen to remove macrofaunal specimens. Sediment particle size distribution was determined for the sand fraction by use of a Wentworth screen series and for the silt-clay fraction by the pipette method⁵.

TEST SPECIES

Test specimens were collected with a bottom dredge from Yaquina Bay, Oregon and removed from the sediment by sieving through a 1.0 mm screen. The five species used in each experiment included the pelecypods, *Protothaca staminea* and *Macoma inquinata*; the polychaete, *Glycinde picta*; and the amphipod, *Paraphoxus epistomus*. The fifth species was one of the following cum-

TABLE 1. SOURCE AND PARTICLE SIZE DISTRIBUTION OF SEDIMENT USED IN BENTHIC BIOASSAYS

Experiment Number	Sediment Type	Sediment Size Distribution				Collection Site
		%Sand	%Silt	%Clay	Mean Grain Size (μ)	
1	Yaquina Bay Control	98.7	0.3	1.0	209	44°37'39"N, 124°02'30"W
2	Yaquina Bay Control	98.6	0.5	0.9	204	
	Fraction of Control:					
	Silt	3.7	93.6	2.7	26	
	Very Fine Sand	87.0	9.8	3.2	69	
	Fine Sand	100.0			188	
	Medium Sand	100.0			272	
	Coarse Quartz Sand	100.0			859	
	Very Coarse Quartz Sand	100.0			1395	
	Control Fractions - Quartz Sand Composite	86.3	13.0	0.7	259	
3	Yaquina Bay Control	98.9	0.3	0.8	202	47°31'07"N, 122°18'18"W
	Duwamish River Turning Basin	24.2	64.3	11.5	21	47°33'24"N, 122°20'31"W
	Duwamish River Slip No. 1	14.6	60.4	25.0	12	47°35'12"N, 122°21'32"W
	Duwamish River Mouth	29.7	57.5	12.8	26	47°35'41"N, 122°21'42"W
	Elliott Bay	39.0	51.0	10.0	21	47°35'45"N, 122°23'58"W
	Puget Sound	11.4	45.2	43.7	7	
4	Yaquina Bay Control	99.0	0.3	0.7	203	
	Coos Bay Station I	98.7	0.4	0.9	289	43°22'29"N, 124°12'25"W
	Coos Bay Station II	66.8	25.7	7.5	62	43°23'03"N, 124°13'04"W
	Coos Bay Station III	94.3	3.3	2.4	193	43°23'53"N, 124°12'49"W
	Coos Bay Station IV	96.0	2.1	1.9	203	43°24'42"N, 124°12'59"W

(continued)

Table 1 (continued).

Experiment Number	Sediment Type	Sediment Size Distribution			Mean Grain Size (μ)	Collection Site
		%Sand	%Silt	%Clay		
5	Yaquina Bay Control	98.7	0.5	0.8	196	29°40'41"N, 94°58'12"W
	Houston Ship Channel Station I	5.2	48.0	46.8	6	29°44'30"N, 95°06'28"W
	Houston Ship Channel Station II	2.6	38.6	58.9	4	29°43'30"N, 95°12'50"W
	Houston Ship Channel Station III	11.2	28.5	50.3	7	29°43'24"N, 95°13'59"W
	Houston Ship Channel Station IV	31.0	58.7	20.3	19	29°45'00"N, 95°17'20"W
	Houston Ship Channel Station V	40.3	38.1	21.6	29	
6	Yaquina Bay Control	96.5	1.8	1.7	187	37°17'19"N, 77°15'27"W
	Bailey Creek	41.9	31.5	26.5	29	
7	Yaquina Bay Control	98.4	0.6	1.0	200	46°10'15"N, 123°54'45"W
	Skipanon River	6.2	68.8	25.0	11	
8	Yaquina Bay Control	99.1	0.2	0.7	212	40°29'40"N, 74°15'24"W
	Raritan River	23.1	38.4	38.5	16	

aceans: Diastylis alaskensis, Lamprops quadriplicata, Diastylopsis dawsoni, or Cyclaspis sp., depending upon availability in Yaquina Bay at the time of each experiment. These species represent different feeding types and taxocenes which often dominate continental shelf and estuarine benthic assemblages.

Since the test organisms occurred naturally at the Yaquina Bay sediment collection site, that sediment was used as a control against which the toxicity of sediments from other areas was compared.

BIOASSAY PROCEDURE

The bioassay aquaria were polyethylene boxes (Fusion-Rubbermaid*, No. 1315) with an approximately 25 l capacity and 1200 cm² bottom area (Figure 1). They were supplied with a continuous flow of seawater (0.5 l/min) at ambient temperature and salinity (9.5 - 16.8°C, 23.5 - 32.7 ‰ during the experiment series).

Eight experiments were conducted from May 1976 until April 1977. The basic design was to place a 28 mm layer of control sediment on the bottom of each aquarium. Test organisms were randomly distributed so that each tank contained 20 individuals of each of the 5 species. They were allowed to "acclimate" for a 48 hr period during which dead or lethargic specimens were replaced. Treatments were randomly assigned to the aquaria after the acclimation period. The test sediment was then introduced by distributing it evenly over the water surface and allowing it to settle for 1 hr while the seawater was turned off. After 1 hr the normal flow resumed and the dissolved and suspended fractions were flushed out. The solid or settleable fraction remained as an even layer on top of the control sediment. After 10 days surviving individuals were recovered by sieving the sediment through a 0.7 mm screen and counted.

STATISTICAL ANALYSIS

Differences in mean survival between the control and test sediments were compared for the individual species and the entire assemblage. Dunnett's procedure⁶ for comparing more than one mean with a control was used for experiments 1, 3, 4, and 5. Student's "t" was used for experiments 6, 7, and 8 which involved only one experimental treatment. Since the objective was to determine if survival was less than in the control, one-tailed Student and Dunnett "t" tables were used to determine significant differences.

RESULTS

EFFECTS OF BURIAL

The first experiment was designed to determine the effects of burial by Yaquina Bay sediment. Sediment layers of 5, 10, 15, 20, 25, and 30 mm thickness-

*Mention of trade names does not imply endorsement by the Environmental Protection Agency.

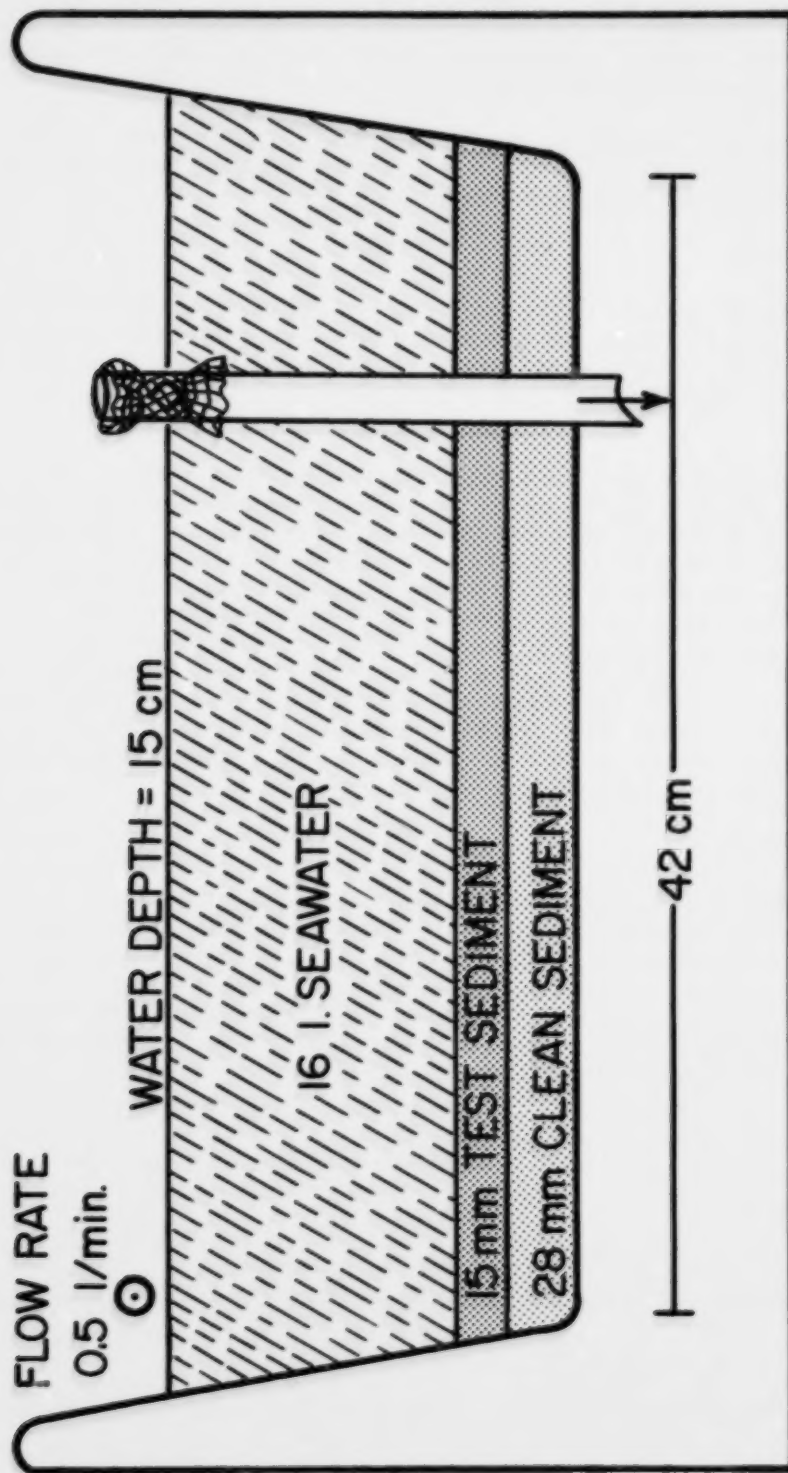


Figure 1. Diagram of the benthic bioassay aquarium.

es were deposited on top of the 28 mm bottom sediment layer. A seventh treatment consisted of a non-burial control, i.e. an overlying layer was not deposited. Replicate bioassays were conducted for each sediment depth and the non-burial control.

Mean survival in the non-burial control for each individual species and for the entire assemblage was not significantly different from survival at any of the burial depths (Table 2). With one exception, the number of survivors in individual aquaria ranged from 89 to 97 specimens ($\bar{x} = 93.5$). An outlier (81 survivors) occurred in one of the 20 mm burial treatments. In the two replicates buried under 15 mm of sediment, 91 and 94 of the initial 100 specimens were recovered. This was considered to be a sufficiently low control mortality for routine toxicity bioassays. After the first experiment only one sediment depth (15 mm) was deposited on top of the bottom layer containing the test organisms. Thus, the control replicates received 15 mm of Yaquina sediment on top of 28 mm of Yaquina sediment. The experimental replicates received 15 mm of test sediment on top of 28 mm of Yaquina sediment.

EFFECTS OF CHANGES IN SEDIMENT PARTICLE SIZE

The second experiment examined the effects of different particle size distributions. The eight treatments were not replicated. They included Yaquina sediment fractions with mean grain sized of 26, 69, 188, and 272 μ ; coarse (859 μ) and very coarse (1359 μ) quartz sands obtained from an aquarium supply company; a composite of the six preceding sediments (259 μ); and intact sediment (204 μ).

Obvious effects of particle size alterations were found only for the survival of cumaceans in the coarse and very coarse sand fractions (Table 3). Mean recovery for the entire assemblage on the sediment fractions with mean grain sizes between 26 and 272 μ was 89.5 individuals. Within this group, the unsieved control sediment had the lowest recovery (85 individuals). The mean particle size of sediments used in later experiments ranged from 4 - 289 μ . Further evidence that fine grain sediments did not affect survival was obtained in the bioassay of Skipanon River sediment which had 11 μ mean grain size, but no significant difference from the control in the survival of any species or the entire assemblage.

SEDIMENT TOXICITY BIOASSAYS

The last six experiments involved bioassays of sediment from various coastal regions of the United States. All treatments in the first three toxicity bioassays were replicated twice. Sediments collected along a transect from the Turning Basin, Slip No. 1, and mouth of the Duwamish River, and from adjacent Elliott Bay and Puget Sound were used in the third experiment. The fourth and fifth experiments included sediment from four stations in Coos Bay and five stations in the Houston Ship Channel, respectively. There were five replicates of the Yaquina control and the test sediment in the last three experiments. Test sediment from one station in Bailey Creek, Skipanon River, and Raritan River were used in the sixth, seventh, and eighth experiments, respectively.

TABLE 2. SURVIVAL OF A MACROBENTHIC ASSEMBLAGE TEN DAYS AFTER DECOMPOSITION OF YAQUINA BAY (CONTROL) SEDIMENT LAYERS 0-30 mm IN THICKNESS.

Species	Initial Number	Mean Number Recovered Sediment Layer (mm)							
		Non-burial Control 0	5	10	15	20	25	30	
<u>Protothaca staminea</u>	20	20.0	20.0	19.5	20.0	18.0	19.5	19.0	
<u>Macoma inquinata</u>	20	20.0	20.0	19.5	20.0	18.5	19.5	20.0	
<u>Glycinde picta</u>	20	17.5	17.0	18.0	18.5	17.5	16.5	17.5	
<u>Paraphoxus epistomus</u>	20	18.5	19.5	17.5	17.5	18.0	18.0	19.5	
Cumacea	20	19.0	19.0	18.0	16.5	17.0	18.5	15.5	
TOTAL	100	95.0	95.5	92.5	92.5	89.0	92.0	91.5	

TABLE 3. EFFECTS OF CHANGES IN SEDIMENT PARTICLE SIZE DISTRIBUTION ON THE SURVIVAL OF THE MACROBENTHIC ASSEMBLAGE. MEAN GRAIN SIZE (m) OF THE SEDIMENT TYPES IS GIVEN IN PARENTHESES

Species	Initial Number	Number Recovered							Yaquina Control (204)
		Yaquina Silt (26)	Yaquina Very Fine Sand (69)	Yaquina Fine Sand (188)	Yaquina Medium Sand (272)	Quartz Coarse Sand (859)	Quartz Very Coarse Sand (1395)	Composite* (259)	
<u>Protothaca staminea</u>	20	20	20	20	20	20	20	20	20
<u>Macoma inquinata</u>	20	18	19	18	20	20	20	20	18
<u>Glycinde picta</u>	20	17	19	19	16	19	20	20	17
<u>Paraphoxus epistomus</u>	20	15	18	15	18	13	15	14	16
Cumacea	20	19	15	19	14	4	7	19	14
TOTAL	100	89	91	91	88	76	82	93	85

*Composite of equal volume of all test sediments except the intact Yaquina control.

There were no significant differences from the controls in the mean survival of any species exposed to sediment from the Skipanon River (Expt. 7) or any of the four Coos Bay stations (Expt. 4)(Table 4).

The differences between mean survival of total individuals in the controls and in sediment from the Raritan River (Expt. 8), Bailey Creek (Expt. 6), and the five stations in the Houston Ship Channel (Expt. 5) were all highly significant (Table 4). The impact of these sediments was most obvious in the survival of Paraphoxus epistomus and the cumacea. The mean survival of Glycinde picta in the Houston Channel stations III and V replicates and the mean for Macoma inquinata in the Bailey Creek sediment were also significantly different. The Houston Channel station III sediment was the most toxic of any tested in the bioassay experiments. Within the two replicates for that station, only 9 of the initial 80 amphipods and cumaceans survived the 10 day exposure period, while 77 survived in the controls.

There was evidence of spatial differences in the toxicity of sediment along the Duwamish River-Puget Sound transect (Expt. 3, Table 4). Lowest total survival was observed for sediment from the Turning Basin and Slip No. 1. The differences from the control were highly significant for both of these stations and for the Elliott Bay dump site. Mean total survival was not significantly different for Duwamish River mouth sediment. It was significantly different for Puget Sound station, although none of the individual species means differed significantly from the controls.

Mean survival of cumaceans was not significantly less than the control for any of the Duwamish River, Elliott Bay, or Puget Sound sediments (Expt. 3, Table 4). However, only between 2 and 13 ($x = 8.6$) cumaceans survived in the individual aquaria. The range of cumacean survival for the Yaquina Bay controls in all experiments was 14 - 20 ($x = 17.5$). Because these ranges do not overlap, we suspect that sediment along this transect may be toxic to cumaceans even though the means based on two replicates were not statistically different from the experiment 3 control.

The sediment toxicity experiments revealed obvious interspecific differences in sensitivity. Protothaca staminea was not affected by any of the test sediments. The survival of both Glycinde picta and Macoma inquinata was significantly less than the control in only two instances and crustaceans were always more sensitive than the polychaete or molluscs. The statistical significance of the difference between mean survival of Paraphoxus epistomus in the control and test replicates was the same as that of the entire assemblage in 16 of the 17 bioassays.

DISCUSSION

The solid phase of sediments from the Duwamish and Raritan Rivers, Bailey Creek, and Houston Ship Channel retained sufficient toxicity to cause the acute mortality of benthic invertebrates. If such sediments were introduced in large quantities into the sea, the dump sites could become significant sources of marine pollution. The ultimate ecological impact of polluted sediment disposal can only be determined through field or laboratory studies of chronically ex-

TABLE 4. MEAN SURVIVAL OF THE MACROBENTHIC ASSEMBLAGE IN SEDIMENT TOXICITY BIOASSAYS
(Twenty individuals of each species were initially placed in each replicate.)

Experiment Number	Sediment Type	Number of Replicates	Mean Survival					
			Total	Protothaca staminea	Macoma inquinata	Glycinde picta	Paraphoxus epistomus	Cumacea
3	Yaquina Control	2	87.5	19.5	19.5	14.0	19.5	14.0
	Duwamish Turning Basin	2	69.0**	20.0	17.0	17.5	4.0**	10.5
	Duwamish Slip No. 1	2	65.0**	20.0	13.0*	16.0	9.0**	7.0
	Duwamish Mouth	2	81.5	20.0	16.0	17.0	17.0	11.5
	Elliott Bay	2	71.0**	20.0	17.5	15.5	12.0	6.0
	Puget Sound	2	76.0*	20.0	16.5	14.0	17.5	8.0
4	Yaquina Control	2	94.0	20.0	18.5	19.5	19.0	17.0
	Coos Bay Station I	2	91.0	20.0	19.5	20.0	18.5	13.0
	Coos Bay Station II	2	92.0	20.0	19.5	18.0	18.5	16.0
	Coos Bay Station III	2	93.0	20.0	19.5	18.5	18.5	16.5
	Coos Bay Station IV	2	94.5	20.0	19.5	19.0	18.0	18.0
5	Yaquina Control	2	98.0	19.5	20.0	20.0	20.0	18.5
	Houston Channel Station I	2	80.0**	20.0	20.0	20.0	13.5*	6.5**
	Houston Channel Station II	2	85.0**	19.5	20.0	20.0	13.5*	12.0*
	Houston Channel Station III	2	58.5**	18.0	20.0	16.0**	0.5**	4.0**
	Houston Channel Station IV	2	75.0**	20.0	20.0	19.5	6.0**	9.5**
	Houston Channel Station V	2	77.0**	20.0	20.0	17.0**	7.0**	13.0
6	Yaquina Control	5	96.6	20.0	20.0	18.4	18.2	20.0
	Bailey Creek	5	81.2**	20.0	17.0*	17.6	12.2**	14.4**
7	Yaquina Control	5	91.8	20.0	20.0	17.2	18.4	16.2
	Skipanon River	5	90.0	20.0	19.4	19.6	16.6	14.4
8	Yaquina Control	5	93.8	20.0	19.8	16.8	18.8	18.4
	Raritan River	5	79.6**	20.0	19.2	17.0	9.4**	14.0**

*p<0.05

**p<0.01

posed biological communities. However, the type of short term bioassay described here can provide data useful in the regulation of dumping activities.

The selection of appropriately sensitive benthic species is essential to the success of this bioassay in a regulatory program. The Implementation Manual published by the Corps of Engineers² recommends that the five test species be selected from the natural dominants of benthic assemblages in the vicinity of the dump site. Because of the response of Paraphoxus epistomus in our experiments, the Manual identifies infaunal amphipods as especially appropriate. The other test species must represent different taxonomic and trophic groups. If sublethal phenomena such as bioaccumulation are to be examined, it would be desirable to include species like Protothaca staminea which can be expected to survive the exposure period.

Laboratory cultures exist for relatively few benthic species. Our experience has shown that with reasonable care it is possible to collect test organisms from wild populations and maintain them under control conditions with low mortality. Since a variety of test species will be used in different coastal regions, the Implementation Manual suggests that a mysid shrimp of the genus Mysidopsis or Neomysis be included for inter-bioassay comparisons. These mysids can be maintained in continuous culture^{7, 8}.

The test assemblage used in our experiments showed little, if any, sensitivity to burial under 15 mm of sediment or to alterations in grain size distribution. This is undoubtedly not true for all benthic organisms. The effects of these factors must be determined before other species are used in the bioassay.

The Ocean Dumping Regulations state that dredged material may be dumped only when the discharge will not exceed the "limiting permissible concentration" (LPC), i.e. that concentration which will not cause unreasonable toxicity. It is difficult to apply the LPC concept to the solid phase either in the water column or sediment after it has settled to the bottom. The Implementation Manual concludes that the results of the benthic bioassay provide an operational determination of the LPC. If mean survival in the test sediment is at least 10 percent less than the control mean and if the difference is significant at the 0.05 probability level, the LPC would by definition be exceeded. The percent differences between means which were statistically significant in our experiments ranged from 13.1 to 40.3 percent for the entire assemblage and from 15.0 to 97.5 percent for individual species.

The benthic bioassay has other applications in pollution control. Test sediment could be collected from sewage and dredge material dump sites, ocean outfalls or other benthic habitats suspected of being contaminated. The bioassay could indicate causal relationships between sediment toxicity and alterations in benthic community structure. Many regulatory programs emphasize water quality criteria, but less attention has been paid to sediment quality criteria⁹. Safe sediment concentrations for specific pollutants could be estimated through acute or chronic benthic bioassays. Chemical monitoring could then determine if the sediment criteria are exceeded.

ACKNOWLEDGMENTS

Credits. We thank Lon Bentsen for conducting the sediment particle size analyses. Drs. Robert Olson, Richard Caldwell, and Donald Baumgartner kindly reviewed the manuscript.

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EUTROPHICATION CONTROL:
IMPORTANCE OF INTERNAL PHOSPHORUS SUPPLIES

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ABSTRACT

Simple phosphorus mass balance models describing the relationship between supplies of phosphorus to lakes and resultant lake phosphorus concentrations demonstrate that internal supplies of phosphorus could be important in controlling lake concentrations. Recent investigations show that several areas within lakes could supply significant amounts of phosphorus over short periods of time. These include sediments overlain by anaerobic water, macrophyte communities, and littoral zone sediments especially when stirred by wind-induced turbulence. Chemical analyses of the phosphorus content of surficial sediments show that the sediments act as a significant phosphorus reservoir, but not all the sediment phosphorus is in a form readily exchangeable with overlying waters. Chemical fractionation techniques have been used to separate various phosphorus fractions in sediments. One fraction, denoted non-apatite inorganic phosphorus (Williams *et al.*, 1976a), is thought to represent the sediment phosphorus which is potentially most likely to release into overlying waters. It can account for a large portion of the total phosphorus content of some lake sediments. Examples describing the importance of internal phosphorus supplies show that the restoration of some lakes has been delayed by the feedback of phosphorus from the sediments at critical times during the year.

INTRODUCTION

Recent syntheses of phosphorus and chlorophyll *a* data analyzed over a broad spectrum of lakes demonstrate a significant correlation between the mass or concentration of chlorophyll *a* (algal biomass) in the trophogenic zone of lakes and the total phosphorus content of the same zone. Nicholls

and Dillon (1977) summarized these relationships and showed significant relationships between algal biomass (summertime) measured as average cell volume and total phosphorus at springtime. The implication of these relationships is that there is a close coupling between the phosphorus content of lakes and the production of algae (see Rigler, 1975; Dillon and Rigler, 1974) and that one way to reduce algal concentrations is to reduce the concentration of phosphorus in lakes. This has been the major thrust of many lake restoration projects. Thus an analysis of factors controlling phosphorus concentrations in lakes is important.

The phosphorus content of lakes occurs as a balance between phosphorus supplies to, and losses from, the lake and can be described conveniently as: (Vollenweider, 1976; Sonzogni *et al.*, 1976)

$$\frac{d[P]}{dt} = \frac{J_e}{V} + \frac{J_s}{V} - \rho_w[P] - \sigma_p[P] \quad (1)$$

where $[P]$ is the average phosphorus concentration in the lake; V , the lake volume; J_e and J_s , the supplies of phosphorus to the lake from external and internal sources; and ρ_w and σ_p , the fractional losses of lake phosphorus through the outlet or to the lake bottom.

The sensitivity of lake phosphorus concentrations to supply rates can be easily demonstrated by the following simplification of Equation (1). For the situation in which $J_s = 0$ (no internal supply of phosphorus), water inflow and outflow are steady and equal, and lake volume is constant, the steady state solution to Equation (1) can be written (Rigler, 1975):

$$[P] = \frac{J_e}{Q} (1-R) \quad (2)$$

where Q is the water inflow rate and R the fraction of inflowing phosphorus retained by the sediments. Assuming that R remains constant, any increase or decrease in J_e will cause a corresponding change in phosphorus; doubling the external supply of phosphorus will double the lake phosphorus content. Increasing the supply of phosphorus to the lake from sediments is analagous to increasing J_e without a corresponding increase in Q . This sensitivity of lake phosphorus concentrations to supply rates suggests that internal sources could hypothetically be an important source of phosphorus.

This paper gives an overview of the importance of internal sources of phosphorus in controlling lake phosphorus content, and thus in controlling algal biomass within the lake. Included is a summary of the magnitude of internal supply rates, nature of sources, and characteristics of sediments which might relate to phosphorus release, as well as examples of lake restoration experiments where the lake response has been delayed by internal supplies of phosphorus.

CONCEPTUAL MODEL

Figure 1 is a simplified conceptual model of the internal sources of phosphorus within lakes. Three zones where release might occur include hypolimnetic sediments, epilimnetic sediments, and regions where macrophytes occur. Of these, the macrophyte zone and epilimnetic sediments have a direct link to epilimnetic or euphotic zone waters, hence any release from these regions can immediately stimulate an algal response if other growth factors are not limiting. In contrast, transfer of phosphorus released from hypolimnetic sediments to the euphotic zone can be restricted by the thermocline. Hence this phosphorus pool might not be so readily available except when thermocline erosion occurs as caused by wind storms or cold front passage, or by annual autumnal cooling and subsequent circulation.

General mechanisms by which phosphorus could be transported across the sediment water interface include:

- 1) passive (molecular) diffusion: the mass phosphorus flux is dependent upon the molecular diffusion coefficient for sediment pore waters and the concentration gradient across the sediment water interface.
- 2) turbulent mixing: this mechanism could include transfer by physical mixing of sediments (as generated by wind mixing, bottom currents, or gas bubble movement), or by biological mixing (as from the movement of demersal and benthic organisms).
- 3) biological transfer: transfer of phosphorus could occur as macrophytes absorb sediment phosphorus through root systems, releasing it through leaves or as fish feeding upon benthic food excrete phosphorus. Although not specifically a sediment source, it is worth mentioning that the decomposition of settled macrophytes and phytoplankton, which have not yet been assimilated into the sediments, can supply phosphorus to the overlying waters and therefore tends to act as an internal supply of biologically available phosphorus.

MAGNITUDES OF INTERNAL PHOSPHORUS SUPPLY RATES

Two general approaches have been adopted to quantify the flux of phosphorus across the sediment water interface: 1) in situ investigations and 2) laboratory microcosm experiments. In situ investigations have been of two kinds. In one, portions of the lake bottom and overlying water are isolated from the rest of the lake with chambers. Changes in phosphorus within the chambers are measured over time and related to various properties of the sediments and/or water. In the other, a phosphorus mass balance of the entire lake is established. Changes in the phosphorus mass in the lake which cannot be accounted for by external supplies and losses are attributed to sediment interactions. Laboratory microcosm experiments are generally conducted by removing sediments from the lake with varying degrees of disturbance and incubating the sediments in chambers under controlled conditions in the laboratory. Sediment release is measured as change in phosphorus content of the overlying water over time. A general observation from these kinds of

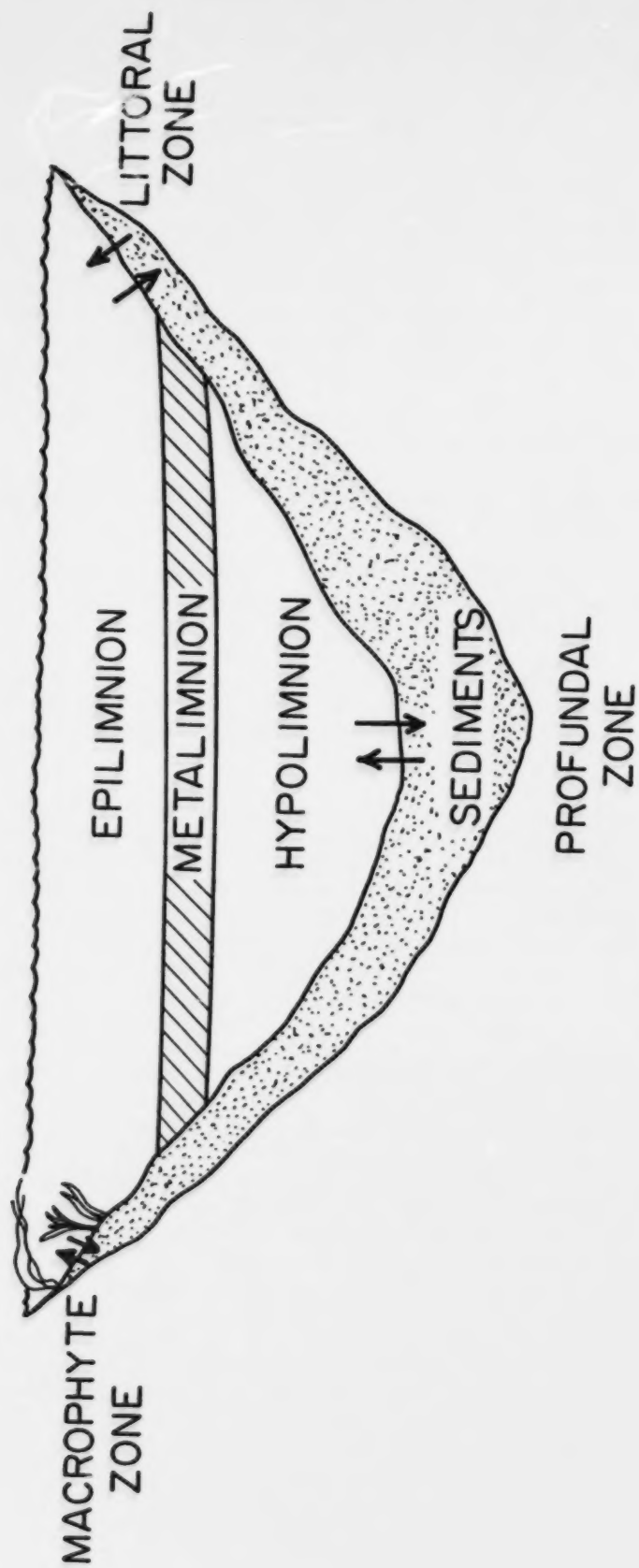


Figure 1. Conceptual diagram of a lake showing various areas where phosphorus can be released from sediments.

experiments is that phosphorus tends to accumulate in sediments when overlying waters are aerobic, but when anaerobic conditions develop, release occurs (Mortimer, 1941, 1942, 1971). Release can occur under aerobic conditions, but the rates are generally negligible. Tables 1 and 2 summarize phosphorus release rates under anaerobic conditions for both in situ and laboratory microcosm experiments. The range of release rates is broad, particularly for the laboratory microcosm experiments. The shorter time period and the various handling and "preparation" techniques associated with laboratory studies might contribute to the broader range of results. The in situ experiments are more likely to provide an indication of long term (months) average phosphorus release from sediments. From this, more accurate estimates of average phosphorus release rates could be computed.

A comparison of the anaerobic phosphorus release rates with annual external phosphorus supplies expressed as a daily rate shows that internal loading can be quite high relative to external loading (Table 1). The anaerobic release rates relate only to the area of lake bottom covered by anaerobic water. To be comparable with external loadings the anaerobic release rates should be normalized to lake surface area. For example, in Shagawa Lake, Minnesota, the bottom area covered by anaerobic water is approximately 50% of the lake area. Therefore the sediment release rate expressed over the lake surface area would be 3.1 - 4.2 mg/m²/day instead of 6.2 - 8.3 mg/m²/day. Even so, the release rates are high compared with external loadings (e.g. for Shagawa Lake, the external loading was $\approx$ 2 mg/m²/day prior to loading reduction).

Another way to demonstrate the importance of internal loading rates is provided by the following example. If a sediment phosphorus release rate of 10 mg/m²/day is assumed and the overlying water column is 10 m thick, the resultant increase in phosphorus concentration in the water column would be about 1 mg/m³/day. This could translate into an increase in chlorophyll *a* content of 1 mg/m³/day. Vollenweider (1968) suggested loading rates in excess of 0.20 mg/m²/yr might be regarded as critical for lakes of 10 m mean depth. This is equivalent to about 0.5 mg/m²/day, about 20 times lower than the above example of sediment release rates.

Experiments summarized in Tables 1 and 2 list the release of phosphorus to overlying waters by mechanisms which are basically diffusional (molecular or turbulent). These mechanisms are by far the most thoroughly investigated, but generally their importance is greatest when anaerobic conditions occur. Another mechanism, less thoroughly investigated but potentially as important, is the transfer of phosphorus from littoral sediments through macrophyte communities. Lie (1977) studied this phenomenon in Shagawa Lake. He isolated areas of lake bottom dominated by macrophytes with plastic cylinders. He measured the changes in phosphorus within the isolation chambers, insuring that phosphorus was not transferred directly from the sediments by covering them with plastic and/or sand. He measured fluxes of 12 - 116 mg/m²/day over a nearly three-month period. These rates are significant but their importance to the open lake water is difficult to assess because the amount of recycling of phosphorus within the macrophyte zone is unknown. Also, in determining the potential significance of macrophyte release, the areal distribution of macrophytes should be considered. Macrophyte communities covered only about 2% of Shagawa's area.

TABLE 1. PHOSPHORUS RELEASE RATES FROM SEDIMENTS ESTIMATED BY MASS BALANCE TECHNIQUES OR BY USING CHAMBERS PLACED IN THE LAKE

Lake	External loading mg P/m ² /day	Release rate mg/m ² /day	Method	Reference
Baldeggersee (Switzerland)		9.5 (1958) 9.9 (1959)	mass balance mass balance	Vollenweider (1968) Vollenweider (1968)
Erie (USA)	3.5	7.4	mass balance	Burns and Ross (1972)
Mendota (USA)		10.8; 7.2	mass balance	Sonzogni (1974)
Norrsviken (Sweden)	11.1 (1961-1962) 1.3 (1975)	1.6 - 9.2	mass balance	Ahlgren (1977)
Sammamish (USA)	2.8	2.6 - 6.2 5.3	<u>in situ</u> cylinders mass balance	Welch (1977) Welch (1977)
Shagawa (USA)	2.0 (1969-1972) 0.25 (1976)	6.2 - 8.3	<u>in situ</u> chambers	Sonzogni et al. (1976) Larsen et al. (1978)

TABLE 2. SEDIMENT PHOSPHORUS RELEASE RATES MEASURED IN
LABORATORY MICROCOSMS UNDER ANAEROBIC CONDITIONS

Lake	Phosphorus release rate (mg/m ² /day)	Reference
Warner (Massachusetts)	1.2	Fillos and Swanson (1975)
Furesø (Denmark)	5.8	Kamp-Nielsen (1974)
Esrom (Denmark)	4.1	"
Esrom (Denmark)	~3.3	Kamp-Nielsen (1975)
Grane Langsø (Denmark)	0.3	Kamp-Nielsen (1974)
St. Gribsø (Denmark)	0.4	"
Bodensee (Germany, Switzerland)	0.65	Banoub (1975)
White (Michigan)	34.2	Freedman and Canale (1977)
Södra Bergundasjön (Sweden)	34	Bengtsson (1975)
Mohegan (New York)	1	Fillos and Biswas (1976)

Cooke *et al.* (1977) indirectly demonstrated the importance of the littoral in supplying phosphorus in Twin Lakes, Ohio, by treating the hypolimnion with alum. They were able to reduce the hypolimnetic content of phosphorus significantly and demonstrated (using sediment oxygen demand chambers) that phosphorus did not leak through the alum blanket in the anaerobic area in the lake. However they observed an increase in epilimnetic phosphorus comparable to that which had developed in the years prior to treatment. They had hypothesized that the epilimnetic phosphorus increase occurred as a result of anaerobic phosphorus release into the hypolimnion followed by transfer into the epilimnion. Since they reduced the anaerobic phosphorus release, yet observed increases in epilimnetic phosphorus, they concluded that the littoral must be an important internal source of phosphorus.

Lee *et al.* (1977) suggest another mechanism which might be important in controlling phosphorus release from the sediments. They measured phosphorus release from sediments in water-filled glass carbuoys under conditions of continuous turbulence keeping sediments in suspension. Although release rates were highest when anaerobic conditions were imposed and release rates were slow when aerobic conditions were imposed, significant amounts of P were released over long periods of time (months) under aerobic conditions. The significance of this mechanism in lakes has not been investigated.

Stauffer and Lee (1973) showed that a significant amount of phosphorus could be mixed from the metalimnion or hypolimnion when turbulence was sufficient to erode the thermocline. The effect of this sort of turbulence (high intensity over short duration) can also have a significant effect by mixing littoral sediments into overlying water (Lee, 1973). In Shagawa Lake, Larsen *et al.* (1978) calculated how much phosphorus might be transferred from the stratified zone when the mixed zone deepened after windstorms (Table 3). Phosphorus increases in the mixed zone after the windstorms were significantly higher than expected from this transfer. They estimated that 500 - 900 kg of phosphorus might have originated from the littoral when windstorms occurred during the summers of 1974 and 1975. These releases were sufficient to increase Shagawa Lake's average phosphorus content 10 - 15 mg/m³ within a few days.

TABLE 3. SUMMARY OF TRANSFER OF PHOSPHORUS FROM STRATIFIED TO MIXED ZONES IN SHAGAWA LAKE, MINNESOTA RESULTING FROM THERMOCLINE EROSION. (from Larsen *et al.* 1978)

Date	Mixed Zone		Stratified Zone	
	Observed Change	Expected Change (kg)	Observed Change	Expected Change (kg)
1974				
7/23-7/30	+2030	+1110	-1190	-1110
1975				
7/20-8/5	+200	+280	-120	-280
8/5-8/12	+1180	+540	-630	-540
8/12-8/19	+550	+40	-50	-40

These examples demonstrate that the sediments can provide significant amounts of phosphorus to overlying waters when appropriate conditions occur. The following section describes some of the characteristics of sediments relating to their potential as a reservoir of phosphorus.

LAKE SEDIMENT PHOSPHORUS CONTENT

The phosphorus content of material sedimented to lake bottoms generally ranges from about 1 to 6 mg/g dry sediment (Table 4). Although surface sediments contain 90 - 95% water (by weight), the amount of phosphorus in the upper 10 cm is sizable. For sediments whose water content is 95% (by weight),

TABLE 4. TOTAL PHOSPHORUS CONTENT OF SEDIMENTS
IN SELECTED LAKES IN NORTH AMERICA

Lake	Total phosphorus (mg/g dry wt)	Core depth	Reference
Sammamish	2 - 5	40 cm core	Welch (1977)
Lower St. Regis	0.5 - 1.4	35 cm core	Fuhs <i>et al.</i> (1977)
Huron	~1 - ~2	50 cm core	Kemp <i>et al.</i> (1972)
Ontario	~1.2 - ~3.0	50 cm core	Kemp <i>et al.</i> (1972)
Erie	~1 - ~2	50 cm core	Kemp <i>et al.</i> (1972)
	0.19 - 2.9	top 3 cm from 48 sites	Williams <i>et al.</i> (1976b)
Monona	~1 - ~2.2	100 cm core	Bortleson and Lee (1975)
Washington	~1 - >6	40 cm core	Shapiro <i>et al.</i> (1971)
Shagawa	1 - 5	160 cm core	Bradbury and Waddington (1973)

TABLE 5. PHOSPHORUS CONCENTRATIONS IN PORE WATERS OF VARIOUS LAKES

Lake	Dissolved Phosphorus (mg/l)	Reference
Södra Bergundasjön (Sweden)	1.16	Bengtsson (1975)
White (Michigan)	2 - 5.5	Freedman and Canale (1977)
Ontario (U.S.A., Canada)	0.055 - 1.04	Bannermann <i>et al.</i> (1974)
Kinneret (Israel)	0.01 - 0.069	Serruya <i>et al.</i> (1974)
Shagawa (Minnesota)	up to ~4.5	Schults (unpublished)

whose sediment specific gravity is 2.5 g/cc and phosphorus content is 2 mg/g (dry weight) ~10 g of phosphorus occur in an area of 1 m² to a depth of 10 cm. If diluted in a water column 10 m deep, the resultant water column phosphorus concentration would be about 1 mg/l. As a comparison, this is equivalent to about 20% of the phosphorus concentration of municipal wastewater which has been subjected to secondary treatment. Although turbulence sufficient to suspend 10 cm of sediments is unlikely, gradual mixing of the sediments to depths greater than 10 cm often occurs (Lee, 1970) therefore this zone might be considered potentially interactive with overlying waters.

Although a significant quantity of phosphorus is present in the surficial sediments, not all is in a form which can readily interchange with lake water. The form most likely to exchange with lake waters is phosphorus dissolved in the pore water. Measurements of pore water phosphorus indicate that concentrations are often as high as several mg/l (Table 5), but this amount is small compared with that in the solid phase. Because lake water phosphorus concentrations are significantly lower than pore water concentrations, gradients of dissolved phosphorus across the sediment water interface can be quite high, providing a potential for significant transfer. For example, dissolved reactive phosphorus gradients measured at the sediment water interface in Shagawa Lake were ~1/mg/l/cm; release rates of 6 - 8 mg P/m²/day have been measured under anaerobic conditions in submerged chambers (Sonzogni *et al.*, 1977). However, at these release rates, a reservoir of dissolved phosphorus can be relatively quickly depleted: at a release rate of 5 mg/m²/day, a pore water reservoir 10 cm deep whose phosphorus concentration is 1 mg/l would be depleted within ~20 days. Thus, over the long run, in order for continued release, this pore water phosphorus must be replenished from particulate phosphorus.

Williams *et al.* (1976a) suggested that sediment phosphorus be operationally divided into 3 components based upon chemical extraction techniques. These three components are "apatite phosphorus", "nonapatite inorganic phosphorus" and "organic phosphorus". Organic phosphorus includes phosphorus chemically bound to carbon directly or through oxygen, and is measured chemically by methods described in Sommers *et al.* (1972). Apatite phosphorus is phosphorus associated with the crystalline structure of apatite, and non-apatite inorganic phosphorus consists of the remaining orthophosphate ions. They are measured according to methods described in Williams and Mayer (1972). This breakdown of phosphorus is similar to that used in describing the phosphorus content of terrestrial soils (Williams and Mayer, 1972). For terrestrial soils, the non-apatite inorganic P (NAI-P) is thought to be the form most readily available for root uptake and might be a valid measure of lake sediment phosphorus available for macrophyte uptake. The NAI-P fraction is also thought to be strongly associated with iron, perhaps as a "ferric oxide-orthophosphate complex" under oxygenated conditions (Williams *et al.*, 1972, 1976a). This complex dissociates under reducing conditions, releasing phosphorus into interstitial waters, and ultimately into the overlying waters. Thus the amount of NAI-P present within the sediments might be a more valid measure of the available sediment phosphorus reservoir than would be a measure of total phosphorus or pore water phosphorus.

Table 6 summarizes the sediment phosphorus fractions for several lakes. In some cases, the fractions were determined in cores so that a vertical distribution is available. These suggest that surface sediments deposited since European settlement in the watershed are enriched with NAI-P relative to sediments deposited prior to European settlement. One effect of European settlement has been to increase the sediment reservoir of a form of phosphorus most likely to exchange with overlying waters.

The magnitude of the NAI-P fractions in surficial lake sediments imply a large reservoir of potentially available phosphorus. In Shagawa Lake about 75,000 kg occur in the upper 10 cm of the profundal zone sediments. The significance of this reservoir can be seen when its magnitude is compared with the amount of phosphorus supplied to the lake annually from wastewater prior to treatment (~5000 kg) or to that estimated to be released from the profundal zone sediments during July and August each year (1000 - 2000 kg) (Larsen *et al.*, 1977). Shagawa Lake is in the process of recovering from the effects of high supplies of phosphorus from wastewater as will be described in the next section.

DELAYED RECOVERY CAUSED BY INTERNAL PHOSPHORUS LOADING

SHAGAWA LAKE

Discussion in the previous sections has shown that sediments can supply significant amounts of phosphorus to lake waters and that there can be a large reservoir of sediment phosphorus exchangeable with overlying waters. The following section shows how these internal reservoirs have delayed the restoration of some lakes.

Shagawa Lake is located in northeastern Minnesota in a forested watershed whose lakes and tributaries are characterized by low nutrient concentrations and whose lakes are characterized by low algal densities. Large blooms of blue green algae (Aphanizomenon flos-aquae, Anabaena circinalis, and Anabaena flos-aquae), high phosphorus and nitrogen concentrations, and anaerobic water below six meters depth have characterized the lake for many years. The stimulus for these conditions was attributed to the large supplies of nutrients entering the lake from the city of Ely (population 5000), situated along the lake's southern shore and discharging wastewater directly to the lake. Wastewater discharge to the lake has occurred since at least 1911 when a primary treatment plant was constructed. European settlement began to occur about 25 years earlier, so that by 1911 the population had grown to ~3500 residents. By early 1973, a wastewater treatment plant was completed to remove essentially all the wastewater phosphorus but to leave concentrations of other elements unaltered as much as possible. The plant has operated successfully for nearly five years, reducing wastewater total phosphorus below 50 µg/l (Larsen *et al.*, 1975, 1978; Malueg *et al.*, 1975; Schultz *et al.*, 1976).

The hydraulic and morphometric characteristics of Shagawa suggest that it should have responded immediately and rapidly to inflow phosphorus reduction (Table 7). It is a shallow lake (5.7 m mean depth) which is rapidly

TABLE 6. PHOSPHORUS FRACTIONS IN SEDIMENTS OF VARIOUS LAKES IN NORTH AMERICA

Lake	Total phosphorus	(mg/g dry weight)			organic phosphorus	Reference
		apatite phosphorus	inorganic phosphorus	non apatite phosphorus		
Erie (mean) (range)	0.879 0.188 - 2.863	0.445 0.144 - 2.277	0.330 0.038 - 2.329	0.110 0 - 0.286	Williams et al. (1976b)	
Ontario (range)	0.500 - 1.500	0.268 - 0.802	0.054 - 0.844	0 - 0.290	Bannerman et al. (1974)	
Shagawa (mean)	3.0	0.23	2.10		Larsen et al. (1978) (seven sites)	
Wisconsin lakes 8 noncalcareous lakes (range)	0.729 - 7.000	0.005 - 0.210	0.102 - 5.800		Williams et al. (1971)	
6 calcareous lakes (range)	0.713 - 1.460	0.092 - 0.246	0.207 - 0.722		Williams et al. (1972)	

TABLE 7. MORPHOMETRIC AND HYDROLOGIC CHARACTERISTICS
OF SHAGAWA LAKE, MINNESOTA

Maximum length:	6.58 km
Maximum width:	2.90 km
Maximum depth:	13.7 m
Mean depth:	5.7 m
Area:	9.24 km ²
Volume:	53 x 10 ⁶ m ³
Altitude of lake mean level:	407.7 m
Water residence time:	0.5 - 1.0 yr

TABLE 8. REDUCTION IN PHOSPHORUS SUPPLIES TO AND RESULTING
LAKE PHOSPHORUS REDUCTION IN SHAGAWA LAKE, MINNESOTA
(From Larsen *et al.* 1978)

Year	Total phosphorus supply kg	Average influent phosphorus concentration µg/l	Average annual lake phosphorus concentration µg/l
1971	6800	71	47.4
1972	6200	100	54.1
1973	2100	20.6	48.7
1974	1500	17.8	31.4
1975	1000	15.3	29.3
1976	900	20.8	29.5

flushed by low phosphorus water from its tributaries, mainly Burntside River. The water retention time ranges from ~ 0.5 - 1 yr and pretreatment phosphorus retention time was less than 0.5 yr, suggesting a nearly complete response within 1.5 - 2 yr after treatment.

Tertiary wastewater treatment for phosphorus removal has reduced the external supply of phosphorus to the lake by nearly 80% (Table 8). The average phosphorus concentration in the inflowing water (all external sources combined) has been reduced from a range of 60 - 100 $\mu\text{g/l}$ during pretreatment years to <20 $\mu\text{g/l}$. If internal supplies of phosphorus were negligible, average lake phosphorus concentrations should be equal to or less than influent concentrations. Average lake total phosphorus concentrations have declined from ~ 50 $\mu\text{g/l}$ pretreatment to ~ 30 $\mu\text{g/l}$ post treatment (annual averages), values presently still higher than the average inflow concentrations.

The seasonal cycle of phosphorus concentrations in Shagawa Lake display an important phenomenon which has apparently delayed its recovery (Figure 2). Each summer lake phosphorus has increased 35 to 50 $\mu\text{g/l}$ from late June to mid-August, an increase of 2000 - 3000 kg. This increase, equivalent to $\sim 1/2$ the 5000 - 5500 kg supplied annually by wastewater prior to treatment, cannot be accounted for by the net import of phosphorus to the lake; the increase is attributed to phosphorus discharge from lake sediments. A large part probably originated from sediments overlain by anaerobic waters, but the littoral might also be an important source especially during windstorms, or in areas where macrophytes are dominant. There has been no appreciable change in the amount of phosphorus discharged during these months in the years subsequent to treatment.

Although the phosphorus content of the lake has declined significantly, the response of the algal community has not been so noticeable (Table 9 and Figure 3), particularly during the late summer. This can be explained by the observation that during pretreatment years, phosphorus was present in excess of algal requirements, hence algal biomass could have attained higher concentrations if not limited by other factors (Figure 4). The reservoir of soluble reactive phosphorus present during pretreatment years is now nearly absent implying that all the phosphorus supplied is consumed by algae and that curtailment of the internal discharges would likely immediately reduce algal concentrations.

LAKE NORRVIKEN, SWEDEN

Lake Norrviken, somewhat smaller than Shagawa Lake, had received both industrial and municipal wastewater for many years. In June 1969, all the wastewater was diverted from the lake, reducing not only phosphorus supplies significantly, but also supplies of nitrogen and other elements. The lake has a surface area of 2.7 km^2 , mean depth of 5.4 m, and a water retention time of about 10 months (Table 10). It too should respond rapidly to phosphorus inflow reduction (Ahlgren, 1972; 1977).

During years prior to diversion, the total phosphorus supply to Lake Norrviken has been ~ 4 $\text{g/m}^2/\text{yr}$; diversion reduced this to ~ 0.5 $\text{g/m}^2/\text{yr}$ corresponding to an influent phosphorus concentration of ~ 80 $\mu\text{g/l}$, an eight-fold

TABLE 9. CHANGES IN AVERAGE TOTAL PHOSPHORUS AND CHLOROPHYLL a IN SHAGAWA LAKE, MINNESOTA, DURING THE ICE FREE SEASON (approximately mid-May to mid-November). Numbers in parentheses are ratios of the value for any particular year to the mean of the 1971 and 1972 values. (From Larsen et al. 1978)

Year	Total phosphorus µg/l	Chlorophyll <u>a</u> µg/l
1971	54.5 (0.94)	20.0 (0.90)
1972	60.9 (1.06)	24.3 (1.10)
1973	50.8 (0.88)	21.2 (0.96)
1974	35.7 (0.66)	11.3 (0.51)
1975	34.6 (0.60)	16.3 (0.74)
1976	35.7 (0.62)	18.5 (0.84)

TABLE 10. MORPHOMETRIC AND HYDROLOGIC CHARACTERISTICS OF LAKE NORRVIKEN, SWEDEN (Ahlgren, 1977)

Surface area:	2.67 km ²
Volume:	14.3 x 10 ⁶ m ³
Maximum depth:	12 m
Mean depth:	5.4 m
Drainage area:	91 km ²
Water retention time:	10 months

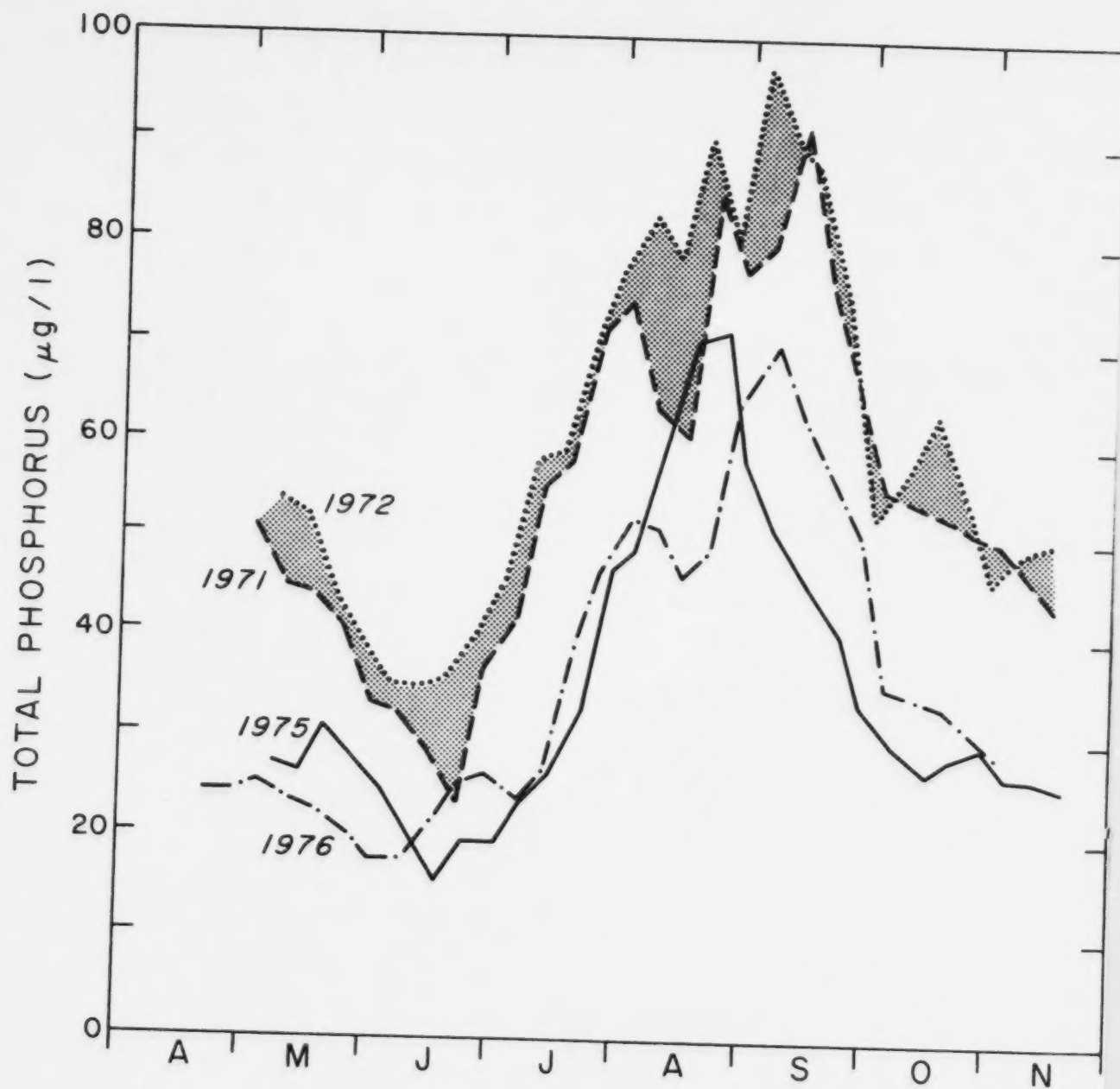


Figure 2. Average total phosphorus concentrations in Shagawa Lake.
(from Larsen et al. 1978)

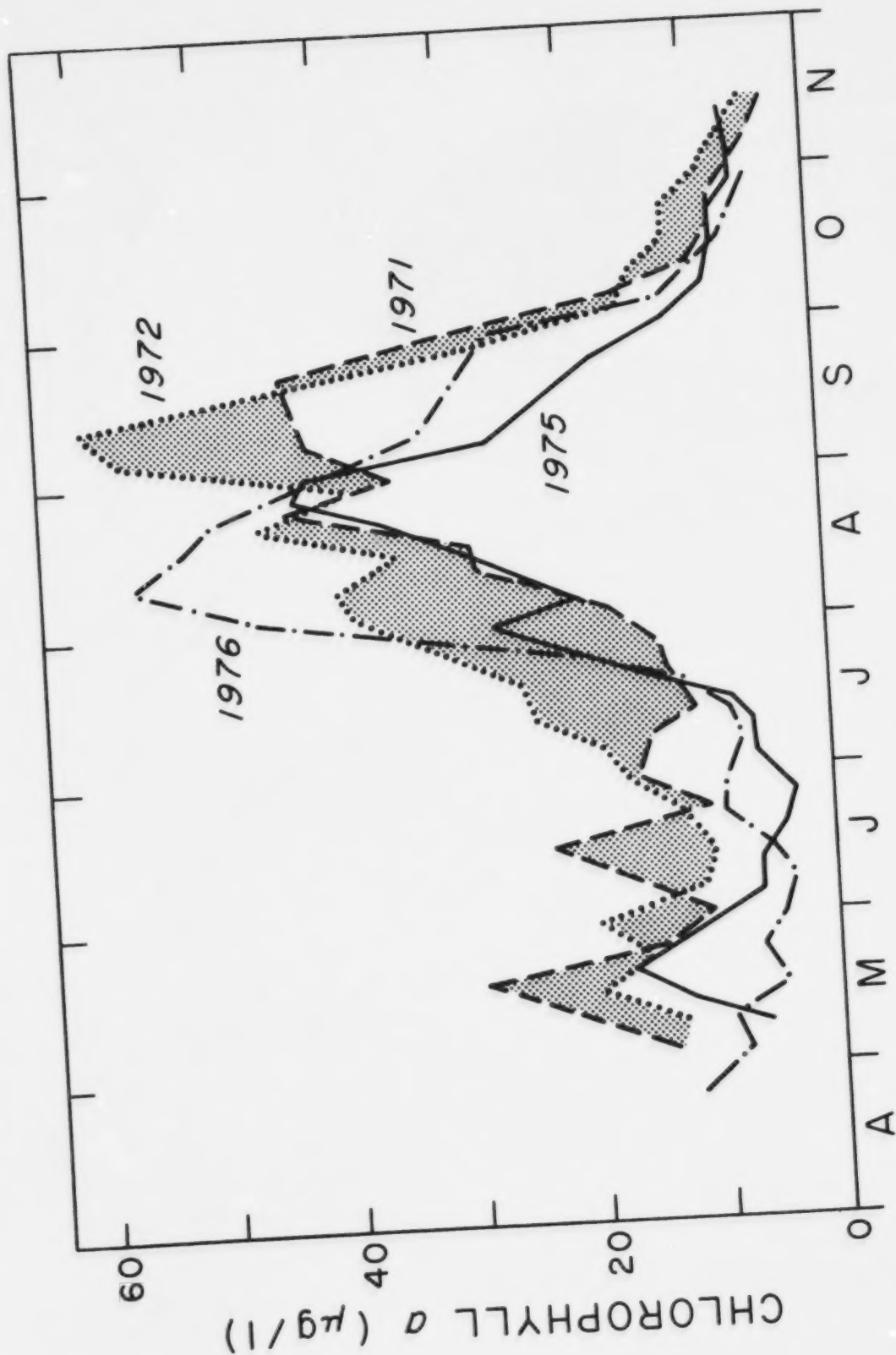


Figure 3. Average chlorophyll *a* concentrations in Shagawa Lake.
(from Larsen et al. 1978).

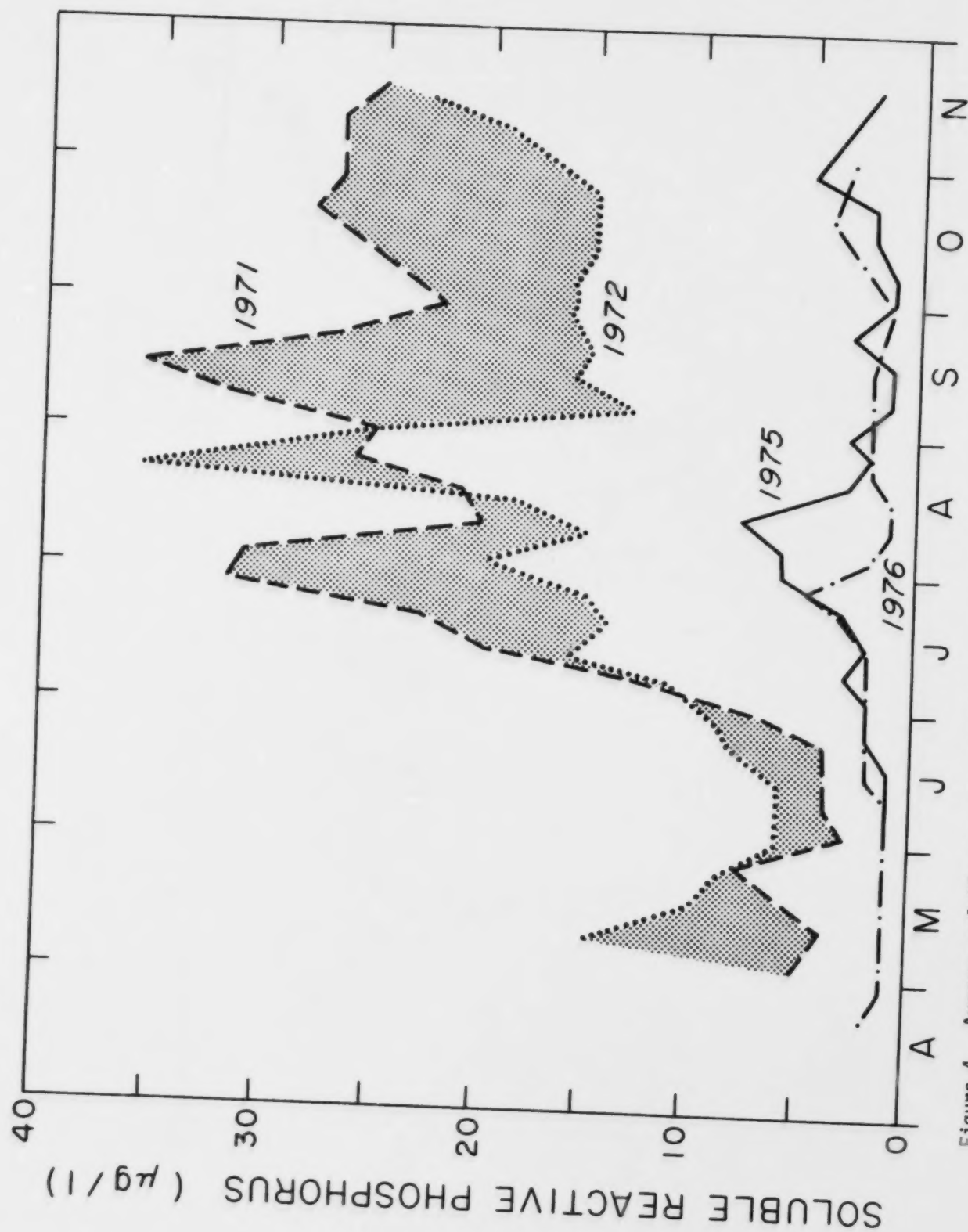


Figure 4. Average soluble reactive phosphorus concentrations in Shagawa Lake.
(from Larsen et al 1978)

reduction in external phosphorus supply. Prior to diversion, the lake had retained about 50% of the inflowing phosphorus in its sediments. If this retention continued after treatment, an average lake concentration of ~ 40 $\mu\text{g/l}$ might be expected. Although this concentration has not been attained, significant reduction in lake phosphorus has occurred, lake phosphorus concentrations declining from 470 $\mu\text{g/l}$ at autumn overturn during 1969 to ~ 150 $\mu\text{g/l}$ at autumn overturn in 1975, and ~ 100 $\mu\text{g/l}$ during mid-1976.

Although during pretreatment years significant amounts of inflowing phosphorus were annually sedimented to the lake bottom, subsequent to treatment, there has generally been negligible retention of phosphorus by lake sediments, suggesting that lake concentrations closer to influent concentrations might be expected. In addition, significant discharge of phosphorus from the sediments has occurred during May-August each year, but the rate of discharge has declined significantly from ~ 9.2 $\text{mg/m}^2/\text{day}$ during 1971 to ~ 1.6 during 1976. This pattern of phosphorus discharge is surprisingly similar to that observed in Shagawa Lake, except that in Norrviken, the internal supply has been declining yearly. Whereas in the case of Shagawa Lake, markedly lowered algal concentrations can be expected if sediment discharge is terminated, in Norrviken, average phosphorus concentrations in the inflow are still quite high (comparable to those for Shagawa Lake prior to phosphorus reduction) so that continued blooms of noxious algae can be expected under phosphorus controlled conditions.

SUMMARY

The supply of phosphorus from sources within a lake can be several times the supplies from external sources for periods of time on the order of months. These internal sources include sediments overlain by anaerobic waters and littoral zone sediments stirred by turbulent activity or populated by macrophyte communities. Chemical measurements of sediment phosphorus content show that the reservoir of total phosphorus within the sediments is high, but that not all the phosphorus is in a chemical form which can exchange readily with overlying waters. Even so, that fraction of sediment phosphorus most likely to exchange with overlying waters can account for a large fraction of the total phosphorus in the sediments. Two examples, the restoration of Shagawa Lake, Minnesota, and Lake Norrviken, Sweden, show that the feedback of phosphorus from sediments can have a significant effect in delaying the recovery of lakes whose external phosphorus supplies have been curtailed.

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THE REGULATION GUIDELINES AND CRITERIA
FOR THE DISCHARGE OF DREDGED MATERIAL:
PREDICTION OF POLLUTION POTENTIAL

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ABSTRACT

Guidelines and criteria have been published for the ecological evaluations of the discharge of dredged and fill material into inland waters and the transportation of dredged material for dumping into ocean waters. These guidelines and criteria were published in the Federal Register, Vol. 40, No. 173, Friday, 5 September 1975, and Vol. 42, No. 7, Tuesday, 11 January 1977, respectively, for inland and ocean dumping. Implementation manuals have subsequently been published and are discussed herein. Relevant dredged material research are also presented. These manuals present evaluative procedures for pollution evaluation.

INTRODUCTION

INLAND DUMPING GUIDELINES

Interim Guidance Published for Implementation of Section 404

Control of the discharge of dredged or fill material to minimize environmental impacts is the requirement of Section 404(b)(1) of Public Law (PL) 92-500 (Federal Water Pollution Control Act Amendments of 1972). Rules and regulations providing this control were published in the Federal Register (Vol. 40, No. 173, Friday, 5 September 1975) by the Environmental Protection Agency (EPA). These regulations specify that EPA, in conjunction with the Corps of Engineers (CE), will publish a procedures manual for the implementation of the regulations. The manual will provide technical guidance for the evaluation of proposed discharges of dredged or fill material into navigable waters as required by Section 404(b) of the Federal Water Pollution Control Act Amendments of 1972.

Pending publications of the procedures manual, District Engineers are to furnish interim guidance to permit applicants concerning the applicability of

specific approaches or procedures to be used in the evaluation process. Consequently, at the request of the Office, Chief of Engineers, the Environmental Effects Laboratory (EEL) of the Waterways Experiment Station (WES) initiated development of this interim guidance for use by District Engineers in evaluating permit applications. This was published and distributed in May 1976 to all Corps field elements in a document entitled "Ecological Evaluation of Proposed Discharge of Dredged or Fill Material into Navigable Waters" (referred to as the "Interim Guidance" and available from WES as Dredged Material Research Program (DMRP) Miscellaneous Paper D-76-17).

The procedures included in the Interim Guidance represent the current state-of-the-art in the dynamically evolving fields of aquatic and sediment chemistry and biology, and attempt to provide a balance between technical state-of-the-art and routinely implementable guidance for performing the evaluation specified in the Federal Register. Evaluation of ecological effects consists of two phases: selection of the appropriate test or evaluation procedures and the interpretation of results for assessment of potential problems. The Interim Guidance defines the applicability of testing procedures to the evaluation specified in the Federal Register and presents limitations in interpreting the results.

The Interim Guidance is applicable to all activities involving the discharge of dredged or fill material into navigable waters. The procedures presented are useful in evaluating the discharge and overflow from hopper dredges; hydraulic pipeline discharges; the discharge and overflow from bottom and end dump barges and scows; and the runoff, effluent, or overflow from a confined land or water disposal area.

General approaches required for ecological evaluation involve estimation of physical effects and chemical-biological interactive effects, both of which are discussed in the Interim Guidance. Procedures for alternate site comparisons are also presented. Detailed procedures include those for conducting the elutriate test and examining the mixing zone that must be used in interpretation of the elutriate test, performing bioassays, conducting total or bulk sediment analyses, and evaluating biological community structure.

The scope and comprehensiveness of the required evaluation may be seen in Figure 1, taken from the Interim Guidance, which shows the sequence of evaluations that must be applied. The Interim Guidance follows the general priority of importance of testing and evaluation procedures and general order of test application given in the Federal Register.

During conduct of the DMRP, it has become apparent that an understanding of the potential for ecological harm from the discharge of dredged or fill material into wetland and aquatic areas requires substantial state-of-the-art improvement in a number of fundamental technological areas. Therefore, such state-of-the-art improvements were included in appropriate DMRP tasks and work units and already have provided the basis for the evaluation procedures as well as the discussions in the applicability and limitations of test results in the Interim Guidance. Contributing DMRP tasks, primarily those in the Environmental Impacts and Criteria Development Project, are listed in Table 1. The appropriate tasks are listed with the respective evaluation category from the Federal Register.

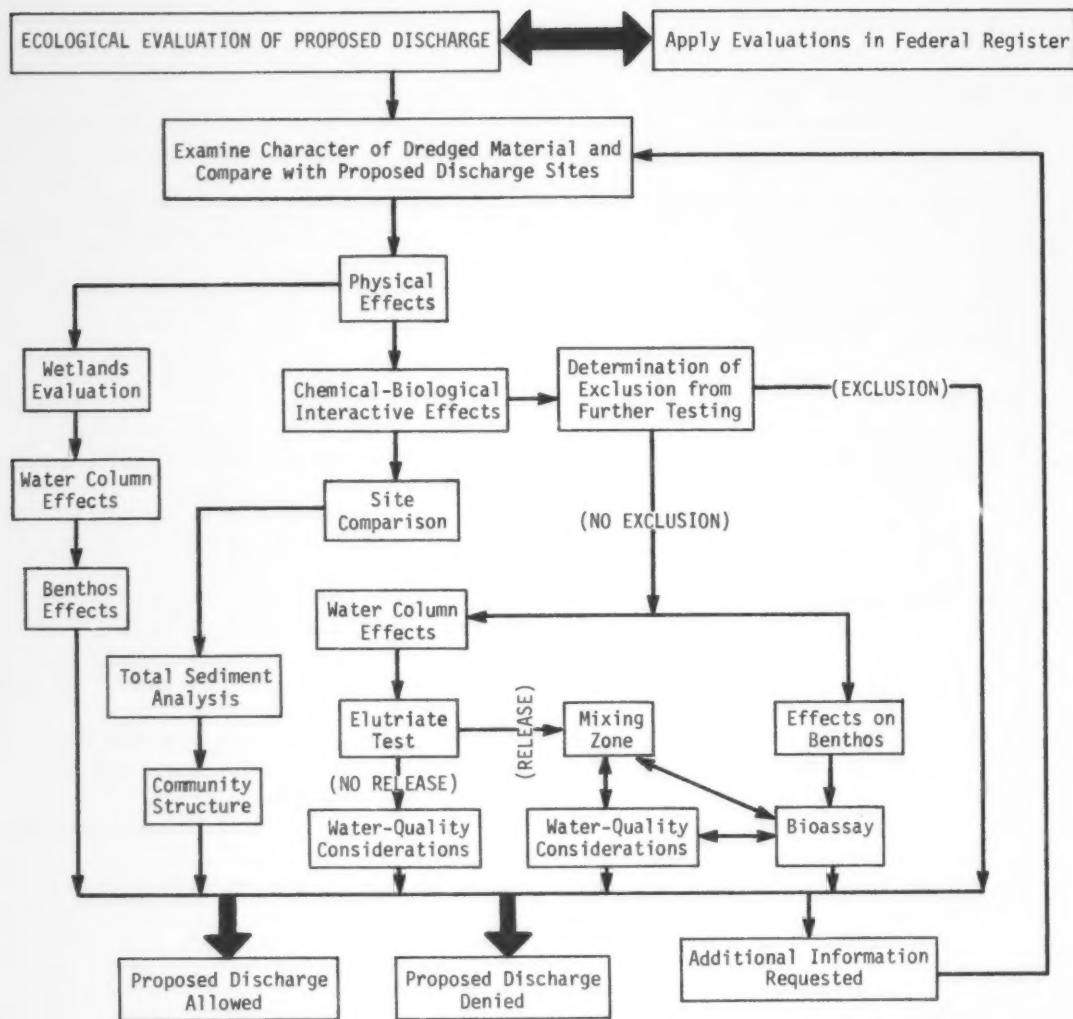


Figure 1

TABLE 1. DMRP TASKS PROVIDING SIGNIFICANT INPUT TO THE INTERIM GUIDANCE

Evaluation Category*	DMRP Task
PHYSICAL EFFECTS	
Wetlands Evaluation	4A Marsh Development
Water Column Effects	1A Aquatic Disposal Field Investigations
	1D Effects of Dredging and Disposal on Aquatic Organisms
Benthic Effects	1A Aquatic Disposal Field Investigations
	1D Effects of Dredging and Disposal on Aquatic Organisms
CHEMICAL-BIOLOGICAL INTERACTIVE EFFECTS	
Water-Column Effects	
Elutriate test	1C Effects of Dredging and Disposal on Water Quality
	1E Pollution Status of Dredged Material
	2D Confined Disposal Area Effluent and Leachate Control
Mixing Zone	1A Aquatic Disposal Field Investigations
	1B Movements of Dredged Material
	1E Pollution Status of Dredged Material
Bioassay	1D Effects of Dredging and Disposal on Aquatic Organisms
	1E Pollution Status of Dredged Material
Effects on Benthos	1A Aquatic Disposal Field Investigations
	1B Movements of Dredged Material
	1D Effects of Dredging and Disposal on Aquatic Organisms
	1E Pollution Status of Dredged Material
Bioassay	1D Effects of Dredging and Disposal on Aquatic Organisms
	1E Pollution Status of Dredged Material
SITE COMPARISON	
Total Sediment	1C Effects of Dredging and Disposal on Water Quality
	1E Pollution Status of Dredged Material
Community Structure	1A Aquatic Disposal Field Investigations

* From Figure 1.

The Interim Guidance, however, is not intended to establish standards or rigid criteria and should not be interpreted in such a manner. Therefore, the document attempts to provide a balance between the technical state-of-the-art and routinely implementable guidance for using the procedures specified in the Federal Register and is expected to provide a continuity among the Corps Districts' and the EPA's evaluation program for Section 404 permit activities.

The Interim Guidance is particularly important in forming a foundation to be augmented by more meaningful and comprehensive evaluation procedures and guidelines as these evolve from current and future DMRP and EPA environmental research. Interagency coordination of the respective programs and development of a joint agency procedures manual is currently being implemented by the EPA/CE Executive Committee on Criteria for Dredged and Fill Material. It is anticipated that the Interim Guidance will be updated routinely through this interagency committee as new and more implementable evaluation procedures are developed and verified. The Interim Guidance will remain in effect until publication of the joint agency procedures manual.

OCEAN DUMPING CRITERIA

Implementation Manual Published for Section 103 of PL 92-532 (Marine Protection, Research, and Sanctuaries Act of 1972)

An ecological evaluation of the proposed discharge potential for environmental impact is required by Section 103 of PL 92-532 (Marine Protection, Research, and Sanctuaries Act of 1972). Criteria for these evaluations were published in the Federal Register (Vol. 42, No. 7, Tuesday, 11 January 1977) by the EPA. These criteria specified in Section 227.27(b) that the EPA jointly with the CE would publish an implementational manual pursuant to the criteria. The Implementation Manual would provide procedures for the evaluation of the potential environmental impacts of the discharge of dredged material into ocean waters: an evaluation that is required in considering permit applications for the transportation of dredged material for ocean dumping.

The task of developing the specific approaches and procedures to be used in the evaluation process was undertaken by the EPA/CE Technical Committee on Criteria for Dredged and Fill Material (see DMRP Information Exchange Bulletin MP D-76-4, April 1976). At the request of the Office, Chief of Engineers, and the Marine Protection Branch (EPA), the EEL of WES published this manual for the evaluation of permit applications and development of statements of findings.

Preparation and publication of the Implementation Manual was conducted under the technical guidance of Dr. Richard K. Peddicord, EEL. Dr. Peddicord also co-chairs the Bioassay/Bioevaluation Subcommittee of the Technical Committee with Dr. Jack H. Gentile of the Environmental Research Laboratory, EPA, Narragansett, Rhode Island.

The manual was published and distributed in July 1977 to all Corps and EPA field elements in a document entitled "Ecological Evaluation of Proposed Discharge of Dredged Material into Ocean Waters" (referred to as the Imple-

mentation Manual and available from WES as a joint EPA/CE publication). Procedures in the Implementation Manual represent a multidisciplinary effort of both agencies to develop procedurally sound, routinely implementable guidance for complying with the Federal Register. Evaluation of ecological effects consists of two phases: selection of the appropriate tests or evaluation procedures and the interpretation of results for assessments of potential problems. The Implementation Manual defines the applicability of testing procedures to the evaluations specified in the Federal Register and presents limitations in interpreting the results.

The Implementation Manual is applicable to all activities involving the discharge of dredged material into ocean waters. The procedures presented are useful in evaluating the discharge from hopper dredges and from bottom- and end-dump barges and scows.

General approaches required for ecological evaluation involve estimation of potential impacts of the liquid, suspended particulate, and solid phases of dredged material; estimation of the bioaccumulation potential; and estimation of initial mixing. Detailed procedures include sediment and water sample collection, preparation, and preservation; chemical analysis of the liquid phase; bioassays of liquid, suspended particulate, and solid phases; estimation of bioaccumulation potential; the estimation of initial mixing, evaluation of prohibited materials; and interpretation of tract contaminant requirements.

The scope and comprehensiveness of the required evaluation may be seen in Figure 2, taken from the Implementation Manual, which shows the sequence of evaluation that must be applied. The Implementation Manual follows the general priority of importance of testing and evaluation procedures and the general order of test application given in the Federal Register.

During the conduct of the DMRP, it became apparent that an understanding of the potential for ecological harm from the discharge of dredged material into aquatic systems requires substantial state-of-the-art improvement in a number of fundamental technological areas. Therefore, such state-of-the-art improvements were included in appropriate DMRP tasks and respective work units and already have provided the basis for the evaluation procedures as well as the discussion of the applicability and limitations of test results in the Implementation Manual. Contributing DMRP tasks, primarily those in the Environmental Impacts and Criteria Development Project (EICDP) managed by Dr. Engler, are listed in Table 2. The appropriate tasks are listed with the respective evaluation category from the Federal Register. Related research by the EPA was coordinated through the Technical Committee.

The Implementation Manual, however, is not intended to establish standards or rigid criteria and should not be interpreted in such a manner. Therefore, the document attempts to provide a balance between the technical state-of-the-art and routinely implementable guidance for using the procedures specified in the Federal Register and is expected to provide a continuity among the Corps Districts' and the EPA's evaluation programs for Section 103 permit activities.

The Implementation Manual is particularly important for forming a foundation to be augmented by more meaningful and comprehensive evaluation procedures

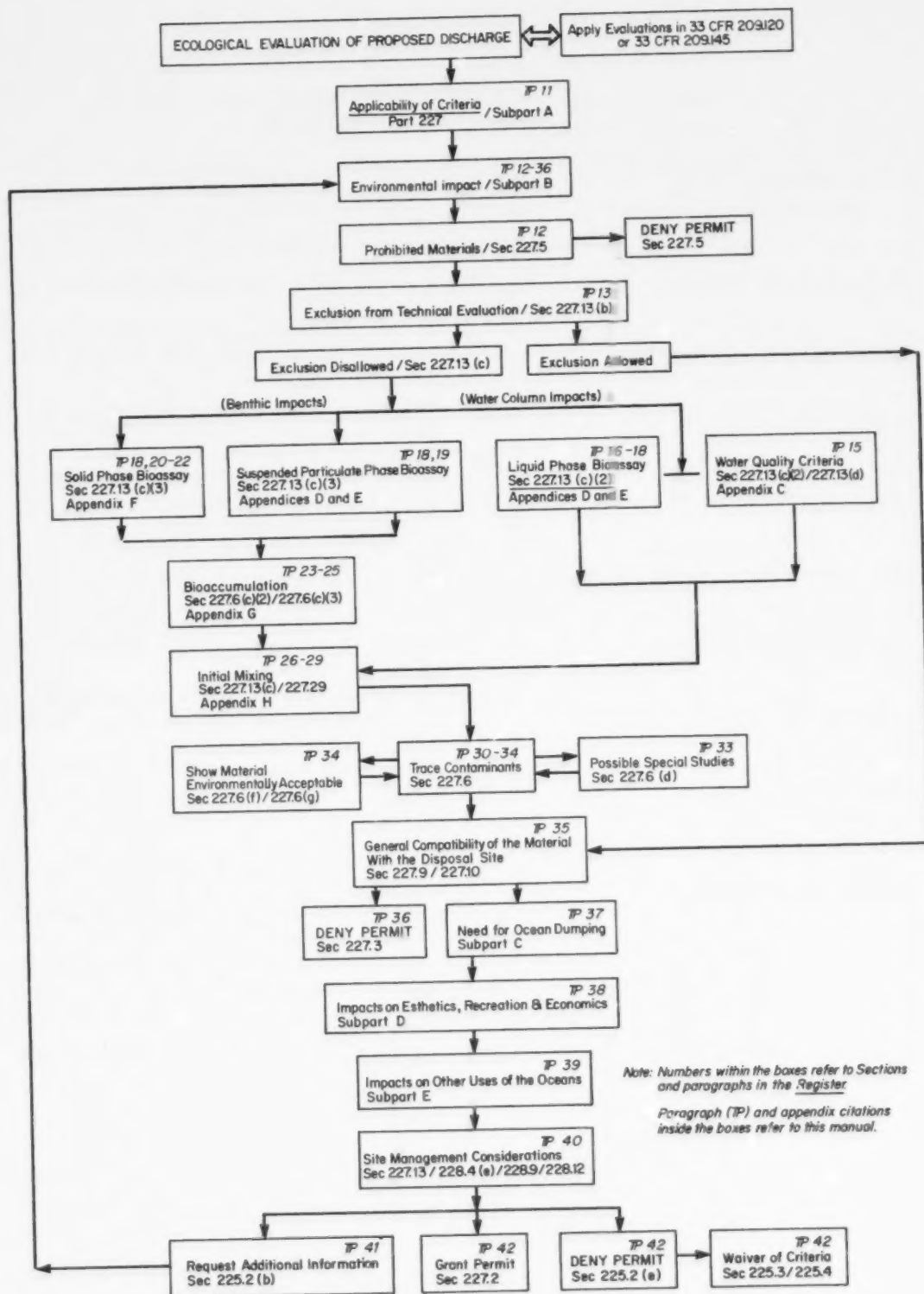


Figure 2

TABLE 2. DMRP TASKS PROVIDING SIGNIFICANT INPUT
TO THE IMPLEMENTATION MANUAL

Evaluation Category*	DMRP Task
Liquid Phase Chemical Tests	1C Effects of Dredging and Disposal on Water Quality
Water-Quality Criteria	1E Pollution Status of Dredged Material
	1D Effects of Dredging and Disposal on Aquatic Organisms
Initial Mixing	1E Pollution Status of Dredged Material
	1A Aquatic Disposal Field Investigations
	1B Movements of Dredged Material
Bioassay	1E Pollution Status of Dredged Material
	1D Effects of Dredging and Disposal on Aquatic Organisms
Suspended Particulate Bioassay	1E Pollution Status of Dredged Material
	1D Effects of Dredging and Disposal on Aquatic Organisms
Solid Phase Bioassay	1E Pollution Status of Dredged Material
	1D Effects of Dredging and Disposal on Aquatic Organisms
Initial Mixing	1E Pollution Status of Dredged Material
	1A Aquatic Disposal Field Investigations
	1B Movements of Dredged Material
Bioaccumulation	1E Pollution Status of Dredged Material
	1A Aquatic Disposal Field Investigations
	1D Effects of Dredging and Disposal on Aquatic Organisms
Trace Contaminants	1E Pollution Status of Dredged Material
	1A Aquatic Disposal Field Investigations
	1C Effects of Dredging and Disposal on Water Quality
	1D Effects of Dredging and Disposal on Aquatic Organisms
	1E Pollution Status of Dredged Material

* From Figure 2.

and guidelines as these evolve from current and future DMRP and EPA environmental research. Interagency coordination of the respective programs and the development of the joint agency procedures manual is being implemented by the EPA/CE Technical Committee of Criteria for Dredged and Fill Material. It is anticipated that the Implementation Manual will be updated routinely through this interagency committee as new and more implementable evaluation procedures are developed and verified. The Implementation Manual will remain in effect until publication of a new edition of the joint agency manual.

INTERAGENCY COORDINATION

Publication of the EPA/CE Technical Committee's First Annual Report

The joint Technical Committee on Criteria for Dredged and Fill Material is co-chaired by Dr. Frank Wilkes of the EPA and Dr. Robert M. Engler of the Corps. The First Annual Report presents the first year's effort to coordinate and disseminate results of agency research related to regulatory functions pursuant to Section 404 and 103 of PL 92-500 and 92-532, respectively.

A major goal of the Technical Committee is the development of a comprehensive manual for technical implementation of all ecological testing phases of PL 92-500 and 92-532. (Publication of the Implementation Manual for Section 103 of PL 92-532 is discussed in the preceding paragraphs.) Other objectives of the Technical Committee are to recommend needed research priorities in order to implement fully Sections 404 and 103, establish joint research projects and priorities, conduct joint program reviews, avoid duplication of effort, and exchange and disseminate research results. The Technical Committee will also review and evaluate interim testing procedures promulgated by the CE for immediate implementation by field units. The group was also constituted to make recommendations to top-level agency management.

The Technical Committee was organized as an interagency committee limited to staff who have broad knowledge, responsibilities, and understanding of needs for research programs in dredges and fill material discharge activities. The Technical Committee consists of six subcommittees co-chaired by EPA and CE personnel: The Bioassay/Bioevaluation, Area Definitions, Contaminants, Physical Impacts, Mixing Zone, and Fill Material Subcommittees. The scope of the Technical Committee and respective subcommittees includes all pertinent research (past, present, and future) conducted to determine the potential usefulness of or to modify methodologies to predict and determine ecological impacts. It also includes the assembly and synthesis of technical information for the purpose of developing an implementation manual suitable for conducting the evaluation mandated by both Section 404 and 103 of PL 92-500 and 92-532, respectively.

The following members are currently appointed by the respective agencies:

EPA

Dr. Frank Wilkes, Co-chairman
Dr. William Brungs
Dr. Mark Carter
Mr. William S. Davis
Dr. Jack Gentile
Dr. Harold Kibby
Dr. Paul Lefcourt
Dr. Michael D. Mullin

CE

Dr. Robert M. Engler, Co-chairman
Mr. M. Burton Boyd
Dr. John Harrison
Dr. John W. Keeley
Dr. Richard K. Peddicord
Dr. Roger T. Saucier

Presented in the First Annual Report is a listing of all related EPA and CE ongoing research programs directly related to dredged and fill material regulatory functions. The listing is presented and discussed by each subcommittee in order that there would be no duplication in recommending and assigning priorities for needed research programs. Presented also is a listing and thorough discussion of 16 research areas identified as requirements for complete implementation of Sections 404 and 103, with each area of research assigned an overall priority, projected costs, and duration of study.

The effectiveness of the Technical Committee can best be judged by the program coordination described in the Annual Report and by the research priorities described therein. Other direct measures of effectiveness are the workshops sponsored through the subcommittees to pursue highly specific goals for individual requirements of Section 404 and 103 of the Public Laws. Of equal importance, however, has been the significantly increased level of communication among CE and EPA research elements and field units. This increased communication will lead to a more effective and efficient management of each agency's respective regulatory and research program.

Copies of the report may be purchased from the National Technical Information Service (address: 5285 Port Royal Road, Springfield, Virginia, 22151). In ordering, the NTIS ID number ADA 040 662 should be mentioned.

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DENSIFICATION, TREATMENT, AND MANAGEMENT OF DREDGED MATERIAL DISPOSAL AREAS

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ABSTRACT

Work within the Disposal Operations Project of the Dredged Material Research Program related to the densification and treatment of dredged material and the management of containment areas is described. The process of dewatering/densifying dredged material through progressive trenching is discussed and the results of a major field test are given. Results of laboratory and field tests on the treatment of contaminated dredged material with chemical flocculants are presented. An integrated management approach for containment areas is presented through a generalized decision network.

INTRODUCTION

The U. S. Army Corps of Engineers' Dredged Material Research Program (DMRP) is a comprehensive five-year research program initiated in March 1973 to address problems associated with the disposal of dredged material. The program is being administered by the Environmental Effects Laboratory (EEL) of the U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi. The DMRP is divided into four projects. Most of the engineering or operational research is being conducted within the Disposal Operations Project (DOP). At the meeting in Japan in October 1976, a paper was presented describing DOP work units dealing with dredged material densification and treatment of contaminated material (1). The paper presented here provides an update of the work described in the previous paper, which will be referenced frequently to minimize the length of this paper and to avoid needless repetition.

DREDGED MATERIAL DENSIFICATION

BACKGROUND

Within the scope of the DMRP, the principal reason for dewatering or densifying dredged material is to obtain additional volume in the containment area and thereby increase its service life. Therefore, dredged material densification should not be confused with dredged material stabilization though often times one results from the other. In some instances dredged material can be stabilized (such as by the use of various chemicals), but the volume occupied by the material within the containment area may not be decreased. Two additional benefits of dredged material densification may be the creation of fast land or changing the character of the wet dredged material into a drier more desirable form that may be put to some productive use.

Work within the DMRP has been aimed primarily at dewatering or densifying fine-grained (silt and clay) dredged material. Fine-grained dredged material is the most difficult material to dewater, but it provides the most volume gain when dewatered. In fact, little volume gain is obtained in materials with liquid limits less than about 50 (2). Figure 1 from Reference 2 shows the relationship between volume gained through reduction in water content versus the plasticity of the material.

The state-of-the-art and state-of-the-practice is such that practically any material may be dewatered; the limiting factor for dredged material is usually cost. Certainly a system that is economical for dewatering a foundation for a building may not be at all economical for dewatering hundreds or thousands of hectares within dredged material disposal areas. Therefore, in many cases, cost is the basis for establishing the feasibility of a particular dewatering technique.

In the first paper, all techniques being evaluated by the DMRP were discussed, including low voltage gradient electro-osmosis, vacuum wellpoints, mechanical crust stabilization, capillary wicks, underdrainage, and progressive trenching. Results of all of the investigations will be reported in detail in the report now being prepared on the field studies (3). Based on the results of these studies, it appears that the most economical technique for dewatering dredged material is progressive trenching. For that reason, this technique will be discussed in some detail.

PROGRESSIVE TRENCHING

In the early phases of the DMRP, it was assumed that the relatively thin desiccation crust that developed on most all disposal areas containing fine-grained dredged material inhibited water removal by evaporation from the underlying wet material and was the cause for the material remaining wet for years. However, after observing numerous containment areas, it became obvious that the formation of the crust was not the sole reason for the underlying material remaining at very high water contents. In most instances, the crust observed in the field was relatively thin (less than 0.3 m). But in some cases where the net evaporation (total evaporation minus rainfall) was extremely high, the crust was observed to extend to much greater depths (in some

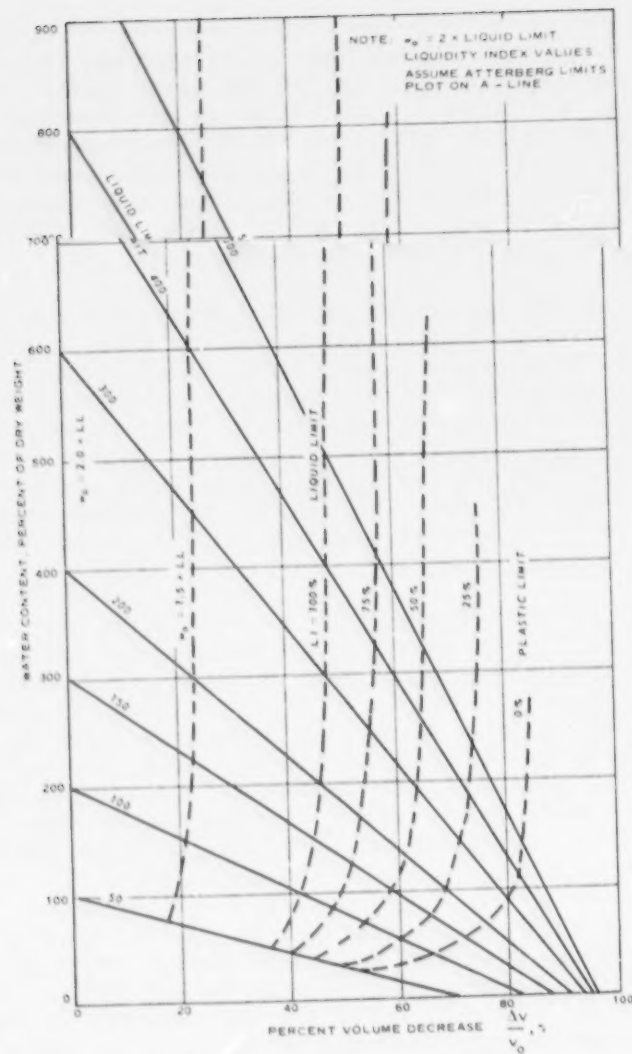


Figure 1. Volume changes with moisture content decreases.

cases greater than 4 m). It became apparent that disposal areas act as catch basins or bathtubs. In many of the areas, the net evaporation rate was low or even negative; therefore, perched water tables developed within the containment areas.

Based on the field observations, the conclusion was that the desiccation crusts extend to the depth of the top of the water table. The validity of this observation was confirmed by controlled crust-formation tests (4). It was decided that a potentially effective and inexpensive method of dewatering fine-grained dredged material would be to promote the formation of the desiccation crust. This would involve the establishment of a good surface drainage system to remove rainfall and other surface water from the site to take advantage of the total rather than the net evaporation rate.

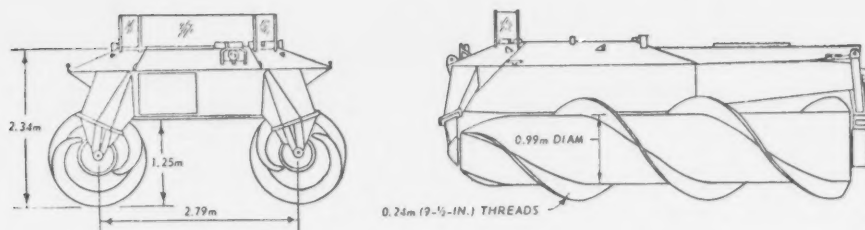
The problem then became how to create a drainage system on the very soft dredged material within the containment areas. In other studies being conducted by the DOP, an inventory and evaluation of low-ground-pressure equipment were made (5). It appeared that the Riverine Utility Craft or RUC (Figure 2) was uniquely suited for providing trenches in the soft material. The RUC, a 5,400-kg amphibious vehicle with 6.25-m-long twin helical screws, creates two semicircular ruts or trenches as it moves across soft ground, thereby providing effective drainage trenches. The RUC was originally developed for military purposes to fill the mobility gap between boats and conventional tracked or rubber-tired vehicles.

A RUC was obtained from the U. S. Marine Corps, and field tests were planned for a disposal site in Mobile, Alabama. The concept of progressive trenching to be evaluated was to provide drainage trenches with the RUC while the material is very soft. The flowline of the trenches must be maintained below the bottom of the desiccation cracks to allow water in these cracks to drain. As the crust becomes thicker and desiccation cracks become deeper, the trenches must be progressively deepened to maintain drainage. It should be remembered that the purpose of the trenches is to remove surface water, not subsurface water. It was thought that as the crust became thicker more conventional equipment could be used for the trenching.

The concept of progressive trenching is not new or completely original to the DMRP. The Dutch have used a similar method known as "soil ripening" for years in polder reclamation (6). In the Netherlands, a vehicle considerably smaller than the RUC and known as the Amphirol is used for initial trenching. The trenches are deepened with larve V-shaped wheels pulled between dikes by cables until more conventional equipment can be used to deepen trenches. Data are being exchanged on the ripening and progressive trenching techniques. A committee such as the one with the Japanese is presently being established by the Corps of Engineers and the European community.

Field Tests

Field tests were initiated in August 1975 at the Upper Polecat Bay (UPB) Disposal Area in Mobile, Alabama. The 34.4-hectare site was created in 1970 and was used for disposal of sediments from maintenance dredging of the Mobile River and Harbor. The material placed in the area was predominantly



RIVERINE UTILITY CRAFT

EMPTY WT (INCLUDING DRIVER & FUEL)	4990 kg	(11,000 LBS)
GROSS WT (DRIVER, FUEL & PAYLOAD)	5900 kg	(13,000 LBS)
LENGTH (OVERALL)	6.25 m	(20.5 FT)
WIDTH (OVERALL)	4.27 m	(14 FT)
HEIGHT (OVERALL, LESS WINDSHIELD)	2.34 m	(7.67 FT)
ROTOR SPACING, CENTER TO CENTER	2.79 m	(110 IN.)
ROTOR DIAMETER (DRUM ONLY)	0.99 m	(39 IN.)
ROTOR DIAMETER (OVER HELIX)	1.47 m	(58 IN.)
ROTOR LENGTH (OVERALL)	5.64 m	(222 IN.)
ROTOR LENGTH (IN CONTACT WITH GROUND, NO RUT)	4.95 m	(195 IN.)
GROUND CLEARANCE	1.25 m	(49 IN.)
FLOATING DEPTH (EMPTY) (WATER)	0.55 m	(21.5 IN.)
FLOATING DEPTH (LOADED) (WATER)	0.61 m	(24 IN.)

Figure 2. Detail and general specification for Riverine Utility Craft

an organic clay sediment (CH) with a liquid limit of about 110 and a plasticity index of about 72. The depth of material in the site when tests were initiated was about 4 m. The crust varied in thickness from 0.005 to 0.2 m and the underlying material was at water contents exceeding the liquid limit. A general plan view of the test site is shown in Figure 3 where individual trenches are labeled A through I. All trenches were graded so water would drain to the weirs. Trench spacings of 15, 46, and 76 m were included to evaluate the effect of varied spacings. The north and south ends of UPB were not trenched in order to conduct other dewatering experiments (3).

The sequence of trenching operations is shown in Figure 4. Although the exact times the trenching operations were performed varied throughout the site, a general schedule will be given here. The initial trenching with the RUC was performed during October 1975. Figure 4a shows the trenches being formed by the RUC. In Figure 4b the effectiveness of the trenches is shown by the water draining from the surrounding area after a rain. Trenches were deepened for the next few months until May 1976 when the average thickness of the crust was about 0.15 m. At this time a marsh dragline (Figure 4c) was used to continue deepening trenches. This machine was a small conventional dragline mounted on a pontoon chassis with 0.76-m-wide tracks. Approximately 5 months later when the depth of the crust averaged about 0.6 m, a conventional dragline and chassis (Figure 4d) was able to operate on mats to continue deepening the trenches. By December 1976 trench depths up to 3.7 m (near original foundation level) were reached adjacent to the south weir. In other areas of the test site, trench depths of 1.8 to 3.6 m were reached.

Performance Predictions

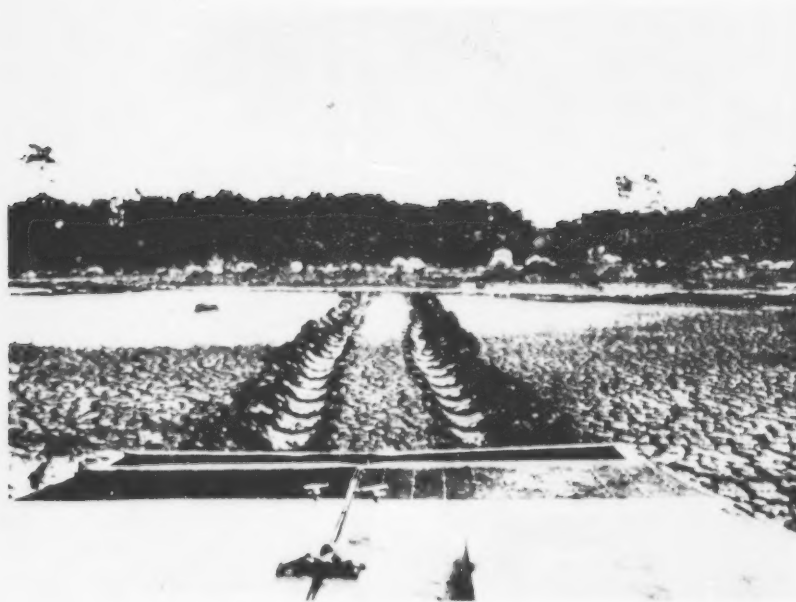
The volume gain within a disposal area should occur from three sources: formation of desiccation crust and cracks, consolidation of underlying dredged



Figure 3. Plan view of progressive trenching test section.

material, and, depending on water table conditions and soil properties, consolidation of the foundation material. Techniques for estimating the magnitude and rates of volume gains have been developed (3 and 7). The magnitude of shrinkage from formation of the desiccation crust can be estimated from a simple test where the slurry is placed in a mold and allowed to dry. From this test the relationship between volume gain and water content can be developed. Couple this information with techniques developed for predicting rates of crust formation and the rate of volume gain can be estimated.

Crust formation changes the effective stress acting on the underlying dredged material and foundation. The effective stresses (and thus consolida-



a. Trenches being formed by the RUC.



b. Water draining from surrounding area after rain.

Figure 4. Sequence of trenching operations.



c. Marsh dragline deepening trenches.



d. Conventional dragline on mats deepening trenches.

tion) will be increased in the dredged material as the water table is lowered. If a perched water table within the dredged material is connected to the water table within the foundation, the foundation material will consolidate as the perched water table is lowered. For the UPB site, it was calculated that there should be a 0.6-m settlement of the surface for each meter of water table drawdown. Additional volume will be obtained from the dessiccation cracks.

Results

Thirteen piezometers survived all trenching operations without damage and trends of drawdown were practically identical for all piezometer locations. The average drawdown was 0.45 m and the average settlement was 0.29 m. The settlement would have been greater if the north and south ends of the test site had been dewatered also. In addition the technique could be refined based on these tests to increase the efficiency of the system. There was no correlation between trench spacing and drawdown. This indicates the spacings were appropriate for removing surface water.

CONCLUSIONS AND RECOMMENDATIONS

Based on the results of the field study and complementary studies, the following conclusions and recommendations are made. More details and guidance on progressive trenching techniques will be given in the synthesis report of all dewatering techniques evaluated (8).

1. Densification and dewatering of fine-grained dredged material can be induced by improving disposal area surface drainage and evaporative drawdown of the internal water table. Densification and dewatering will result from a combination of subcrust dredged material and foundation consolidation under increased effective stress and shrinkage from evaporative drying above the lowered water table.
2. Construction of surface drainage systems by trenching within confined disposal area is operationally feasible. Although the rate of settlement can be estimated, trenching operations must remain flexible to adjust to changing conditions within the disposal area.
3. As dredged material drying and crust formation progress, the trenching system must be progressively deepened to allow continued drainage from the crust and to promote further crust formation.
4. Trenching with the RUC appears to be the best available method to initiate surface drainage trenches in disposal areas with crusts less than 0.1-m thick.
5. Amphibious or marsh chassis draglines are effective in trenching operations when crust thicknesses are in excess of 0.15 m. Lightweight draglines operating on mats can be employed when existing crust thicknesses are in excess of 0.3 m.
6. The magnitude of drawdown was not greatly affected by trench spacing. It is recommended that RUC trenches be spaced close together in order to remove as much surface water as possible. The use of the RUC allows

large numbers of trenches to be formed in a relatively short period of time. When conventional equipment is used, it probably will not be economically or practically feasible to deepen every RUC trench.

7. Results of analyses made to predict the expected amount of sediment from consolidation and shrinkage compared favorably with field-measured behavior.

TREATMENT OF CONTAMINATED DREDGED MATERIAL

BACKGROUND

In the United States, treatment of dredged material prior to disposal has rarely been required. In one instance, treatment for PCBs involving the use of flocculants and activated charcoal was necessary before effluent could be returned to the waterway from a confined disposal area. This is certainly an exception; normally conventional dredged material containment and release of effluents over weirs is sufficient treatment. However, it was realized by the DMRP that there would probably be instances where additional treatment would be necessary and the program would be incomplete if this aspect of disposal was not addressed.

It is well known within the dredging-related community but not generally understood outside the community that dredged material is not sewage sludge. Consequently, treatment processes applicable to sewage sludge or waste water are not always applicable to dredged material. The applicability of conventional treatment processes to dredged material was evaluated early in the DMRP (9). This study verified that most conventional waste water treatment methods are not applicable to dredged material or are impractical because of the relatively low organic content, high solids content, high magnitude and variability of flow, and complex makeup of physical and chemical properties of the material.

On the positive side, this and other studies indicated that practically all contaminants are associated with the solid phase and not the fluid phase of dredged material (9 - 12). Consequently, retention of solids within a containment area generally eliminates the need for further treatment. For this reason, emphasis within the DMRP was placed on treatment involving providing maximum removal of solids prior to discharging effluent back into the waterway. The two most promising methods appear to be filtration and flocculation. Filtration studies have been completed and published (13). Work on flocculants has been completed, but the results have not been published to date. This section of the paper will discuss the results of the flocculation studies. The discussion must be on a very general basis since all data have not been analyzed and final conclusions have not been drawn in all instances. More detailed information will be available at a later date.

LABORATORY STUDIES

Extensive laboratory studies of the effectiveness of flocculants were conducted for the DMRP at the University of Southern California (14). The studies included the following:

1. Investigate the effectiveness of both conventional and polyelectrolyte flocculants for the removal of the fine-sized fraction of dredged materials that are likely to remain in suspension.
2. Determine the optimum dosage required for adequate flocculation of the fines.
3. Correlate the characteristics of sediments with the type and dosage of flocculants.
4. Evaluate the removal efficiency of contaminants in water columns with and without polymer treatment.
5. Evaluate the effectiveness of treatment within the dredge pipe and at the weir.
6. Compare the characteristics of flocculated sediments versus resettled sediments.
7. Study the effect of salinity on the treatment of effluents.
8. Study the possibility of leaching contaminants from flocculated sediments.

The results of the studies were based on tests conducted on 50 types of polymers and conventional coagulants. Extensive laboratory experiments were carried out to screen commercially available polymers and conventional coagulants such as alum and ferric sulfate. It was found that the conventional coagulants are unsuitable due to the large dosages and pH control required to achieve acceptable effluent quality. There is also the problem of carryover of trace metals from these conventional coagulants. Many high molecular weight cationic and anionic polymers were found to be very effective for the treatment of suspensions in the laboratory. Rapid removal of contaminants was observed immediately after flocculation. When a detention time of a few minutes is provided, the concentration of contaminants in the treated effluent can be drastically reduced from the parts-per-million range to the parts-per-billion range.

It was found that the optimum dosage of a polymer is closely related to the level of salinity and initial turbidity of the suspension. A suspension with high salinity and low initial turbidity usually requires less polymer. However, a suspension with high turbidity is easier to clarify by fast floc formation. Treatment within the dredge pipe presents problems in determining the optimum dosage due to the high variability of the material within the pipe as well as requiring more polymer. The containment area actually acts as a buffer and provides a more uniform material of lower solids concentration coming over the weir. Parameters of gross content such as COD, TOC, and particle size of sediments were found to be well correlated with optimum dosage requirements. Therefore, these parameters could be useful in the initial selection of the type of polymer and optimum polymer dosage.

There is no significant difference in the physical properties of resettled sediments with and without polymer treatment in terms of plastic limit, liquid limit, and plasticity index. However, there is a slight increase in the coefficient of permeability for the polymer-treated sediments.

An assessment of long-term mobilization of chemical constituents from polymer-flocculated particles was also conducted to gain additional insight concerning the possibility of release of contaminants to the water column. In most cases, the polymer-treated particles did not show a significant difference in the release of contaminants than that of untreated samples.

FIELD FLOCCULATION TESTS

The laboratory tests indicated that the use of flocculants was an effective treatment method. The problem still remained as to how to apply these findings to actual field operations. For a flocculant to be effective, the chemical must come into contact with the soil particle, then time is required for the flocs to form, and then rather quiescent conditions must be provided for the flocs to settle. These steps are easy to control in the laboratory. A full-scale test was conducted to see how well these factors could be controlled under field conditions (15).

A schematic diagram of the field test is shown in Figure 5. The site selected was an actual dredging project at a freshwater site on a river. An 18-in. (46-cm) dredge was working at the site. The test was designed to evaluate the introduction of the flocculant in the pipeline and at the weir. A booster pump was required because of the relief of the area. Introducing the high molecular weight cationic polymer on the suction side of the dredge was simulated by injecting the chemical on the suction side of the booster pump. Other injection and/or sampling points allowed the evaluation of various retention times within the pipe. Treatment at the weir required an additional containment area to provide relatively quiescent conditions for settling to occur. It is important to note that the polymer selected for use in the field tests (based on a screening of many polymers) did not work well on the sediments evaluated in the University of Southern California studies. This emphasizes that there is no universal flocculant and each case must be evaluated separately.

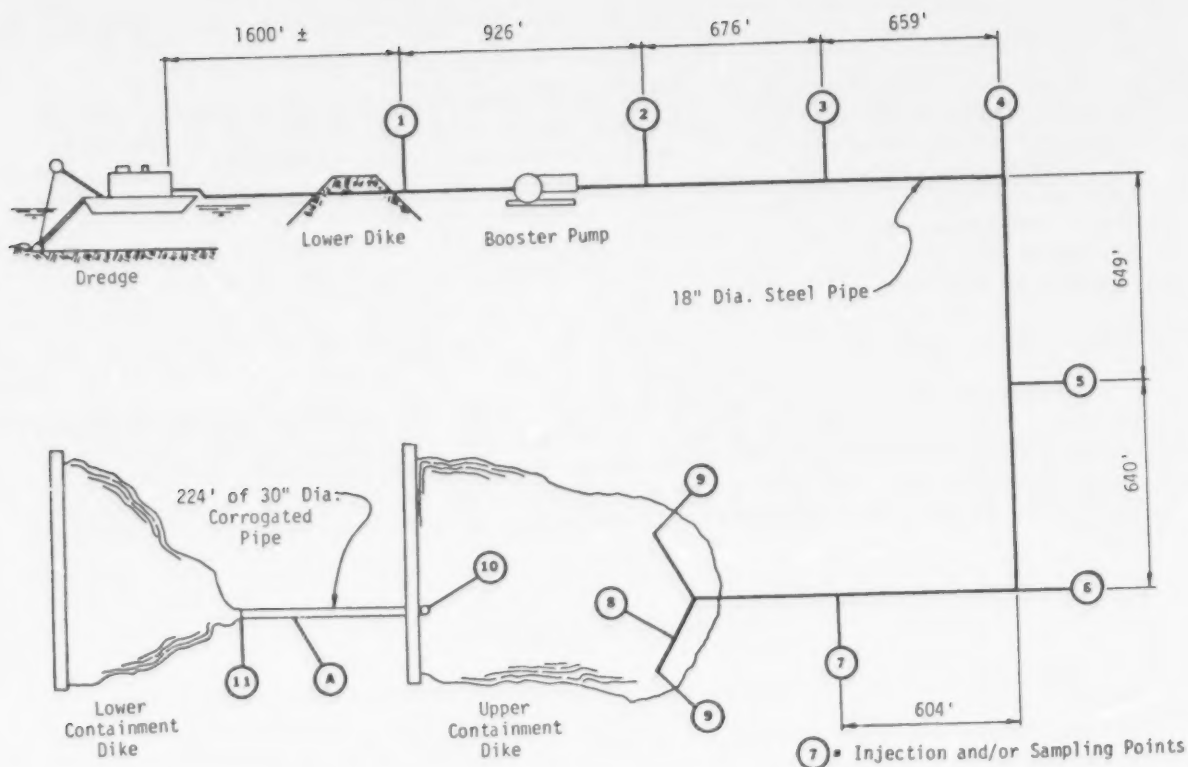


Figure 5. Schematic diagram of field flocculation test.

The supernate of initial samples taken directly from the dredge pipe had high turbidity averaging around 3000 NTU (Nephelometric turbidity units). The polymer dosage used was 20 mg/l. For the particular polymer used in the tests, the residence time in the pipe had little effect because the flocs formed rapidly and were extremely strong. When the concentration of solids in the pipe was near the design concentration, the turbidity of the supernate was drastically reduced (10-15 NTU). However, as solids concentrations varied to either side of the design concentration, the turbidity was reduced to only 1500 NTU. This supports the point made earlier that the side variation in flow and solids concentration in the pipe makes it extremely difficult if not impossible to determine the optimum dosage to provide the desired results.

The tests where the chemical was pumped directly into the dredge pipe identified another problem associated with this method. In order to inject the chemical, a pump must be used to overcome the pressure in the pipe. In most instances a very dilute polymer mixture is desired. This requires very

large quantities of makeup water. For these tests less dilute polymer mixtures than desired were used because sufficient makeup water was not available.

For the tests conducted at the weir, the turbidity of untreated supernates (35-175 NTU) was much lower than that from the discharge at the pipe. Dosages ranged from 10 to 36 mg/l depending on the turbidity level. The turbidity was generally reduced to 5 to 35 NTU. This indicates that some control of the solids concentrations is necessary for effective use of polymers. Problems of injecting the polymer at the weir are minimal when compared to those of injecting into the dredge pipe; for these tests a gravity-feed system was all that was required.

CONCLUSIONS

Flocculation can be an effective method of preventing contaminated effluent from containment areas. Problems of implementing the treatment under field conditions are formidable but can be overcome. Details on implementation are not given here but will be published in Reference 15. Treatment at the weir appears preferable to direct treatment in the dredge pipe.

CONTAINMENT AREA MANAGEMENT

The preceding discussions have related to specific individual research efforts within the DOP to improve disposal operations. However, it has been the philosophy of the DOP that integrated disposal area management must be accomplished if containment areas are to serve their designated purpose, i.e., contain dredged material with the minimum environmental impact. This includes managing the sites to minimize the land areas required for containment. This is also a requirement in recent legislation passed by the U. S. Congress. Section 148 of Public Law 94-487, the Water Resources Development Act states in part that the Corps of Engineers "...shall utilize and encourage utilization of such management practices ... appropriate to extend the capacity and useful life of dredged material disposal areas such that the need for new dredged material disposal areas is kept to a minimum. ..." To assist Corps of Engineers' elements in planning for implementation of the law, the DMRP prepared a special edition of its Information Exchange Bulletin, which included as integrated management approach (17).

Figure 6, extracted from the Bulletin, presents a management decision network. The network was developed to indicate how and where the individual management guidelines being developed by the DMRP may be applied. The diagram is not intended to be a complete decision making network but can be used to identify critical areas where management decisions should be made. Since environmental considerations may dictate the location of a new site or govern the continued use of an existing site, an evaluation of these considerations must be made in developing the overall management scheme. By the end of the DMRP in March 1978, it is believed that practically all of the as yet unanswered questions encountered when following the diagrams will be addressed and proper guidance will be available to make sound engineering and scientific judgments.

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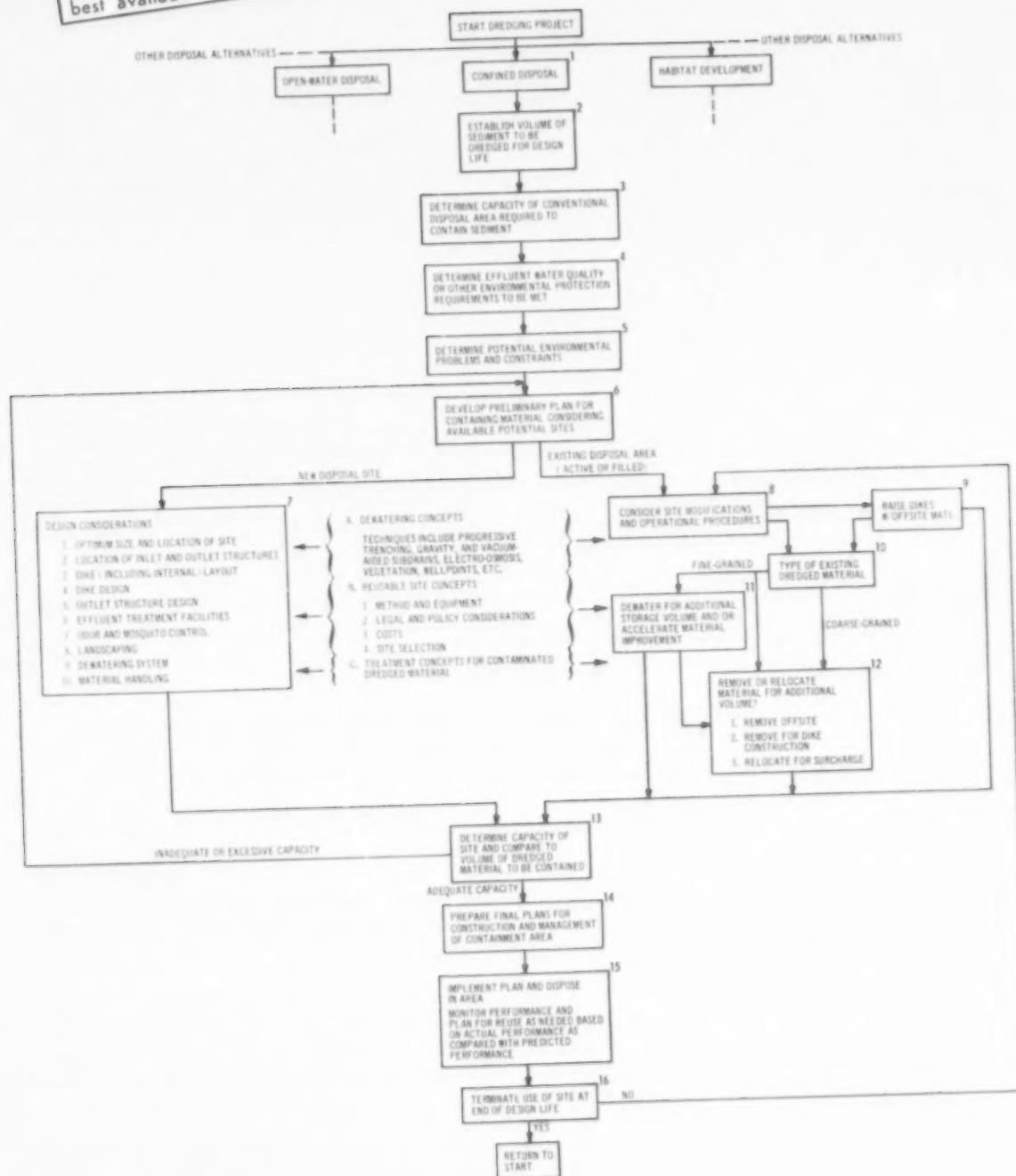


Figure 6. Dredged material disposal - management decision network.

CLOSING REMARKS

Since the SMRP is ongoing, answers to all questions being addressed are not yet available. This paper is intended to familiarize the reader with some of the work and, when possible, present findings. All research in the DMRP will be concluded in March 1978. All reports will be available by October 1978. The DMRP Information Exchange Bulletin is published approximately monthly and provides up-to-date information on the program. The Bulletin will be mailed directly to those requesting it.

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APPENDIX

DREDGING DEMONSTRATION PROJECT: YOKKAICHI, JAPAN A PROPOSAL FOR A JOINT US/JAPAN FIELD PROGRAM

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INTRODUCTION

Exchange of information between the United States and Japan in the area of managing bottom sediments containing toxic substances originated from a 1970 U.S.-Japan cabinet-level meeting on pollution which was held in Tokyo. Both countries recognized the seriousness of the problem at that time, and in the future if left unchecked. Several years of negotiations led to the first technical experts' meeting in Corvallis, Oregon, in November, 1975; a joint communique recommending that the exchange be continued and supported by the two respective governments resulted.

At the first meeting, the possibility of initiating a joint U.S.-Japan project was discussed. At the second meeting in Tokyo during 1976, it was agreed that an area of mutual interest was a demonstration of advanced Japanese dredging technology as it pertained to the removal of sediments containing toxic substances. Initially the project was to have been conducted in the United States but reconsideration of the logistics involved suggested that Japan was a more feasible location, specifically in Yokkaichi Port.

UNITED STATES CONCERNS

The United States is concerned with three major aspects of dredging. These include: 1) the dredge's effectiveness in minimizing the resuspension of bottom sediments, 2) relative efficiencies of different types of dredge systems and 3) treatment techniques applied to return flows. Specific questions to be addressed by a demonstration project should be:

1. What is the minimum water depth in which the various dredge systems can work (oozer dredge, clean up dredge, etc.)?
2. To what depth is the sediment disturbed? For example, is it possible to remove only the top 6 - 10 cm of sediment without substantially disturbing the deeper sediment layers?
3. What are the relative sustained sediment removal rates of specialized vs. conventional hydraulic dredges when sediment is removed from various depths under the same conditions, i.e., sorted and unsorted sediments, clays, organics, etc.?

4. What are the sediment removal efficiencies in dense sediments such as gravel and cobble?
5. What levels of turbidity or suspended solids are created, over what area is the resuspension distributed, and how quickly is it dissipated?
6. What percentage of dredged materials delivered to the disposal site are solids, and how does the percentage vary with sediment type?
7. How do contaminant concentrations and volumes of return flow waters from the disposal area vary among the different dredge systems under the same conditions?
8. What is the cost per cubic meter of sediment removed by the different systems?
9. Considering items 7 and 8, are savings realized with the oozers systems compared to conventional hydraulic systems when it becomes necessary to treat the return flow water?
10. How many operators are required for the specialized equipment and how much crew training is required?
11. What are the concentrations of specific toxicants in the water in the vicinity of the dredge head with respect to ambient levels?

All of the above questions are of concern to the United States. While we have some problems similar to those in Japan, we also have two which differ considerably. The problem of PCB clean-up in the Hudson River is complicated by the fact that the highest concentrations of PCB are located in shoal areas with gravel bottoms which are cluttered with logging and lumber processing wastes. The kepone problem in the James River is unique because, although similar to PCB in some respects, little is known about its specific characteristics in an aquatic medium. The fact that both areas are located in a running water environment is of further concern since downstream effects will occur.

Since the major concern associated with dredging toxic substances is the potential for the dredging activity to result in secondary pollution from the resuspension, dispersion and subsequent resettling of bottom sediments, these are the main areas the demonstration project should address. Associated questions such as dredging production rates, treatment techniques, and cost should be considered also. It is recommended that a joint United States/Japanese demonstration proposal addressing the major concerns be adopted and implemented at the earliest possible date. A possible approach is suggested in the following paragraphs.

PROPOSED DEMONSTRATION

The real danger from secondary pollution due to dredging toxic substances stems directly from the chemical composition of the pollutants themselves and

from the potential for altering their chemical composition as a result of rapid oxygen depletion due to oxidation of organic sediments. The physical characteristics of the substrate being dredged are also important because finer grained sediments have a greater affinity for pollutants than do coarser grained materials because of their proportionally higher surface to volume ratio. The items discussed below are considered important enough to warrant an international field effort yet tractable enough to ensure success in a rather limited time frame.

1. It will be necessary to thoroughly characterize the sediments physically and chemically. This characterization should be consistent with current Japanese standard methods and monitoring design. If such methods are not available then the sediments should be characterized at a number of sites similar to the experimental design proposed by the Japanese scientists for examining benthic organisms. These analyses must describe changes with sediment depth down to the point of maximum dredging depth, so the potential for resuspension might be assessed. Standard particle size fractional analyses and chemical composition with particular reference to total mercury (THg) and PCB should be conducted so that these factors can be accurately correlated. Particle sizing from turbid water samples could be accomplished with a Coulter Counter.

2. Pollutant concentrations in the disturbed water mass could be correlated with turbidity (transmissometer readings) early in the investigation and subsequent measurements might be limited to additional turbidity fluctuations. This would permit many more measurements to be made and thus increase the precision of the results. This research item stems from Mr. E. Sato's report on the excellent correlation between turbidity/suspended solids and concentrations of THg, PCB, etc. (Sato, 1977).

The intensity of movement of turbidity clouds associated with dredging activities are the most readily observed indicators of the bottom dispersion of contaminants. Measurements of the turbidity and suspended solids concentrations of these clouds thus probably offer the most potential for direct determination of their horizontal and vertical area of influence. Data from this investigation should be analyzed by determining correlations between total suspended solids concentrations (mg/l) as a function of light extinction measurement by a beam transmissometer and displayed to show horizontal and vertical extent of the area of influence.

It is recognized that any proposed experimental design may be altered by the specific site conditions, i. e., tide, wind, harbor current characteristics, etc. It should be noted that these conditions can be modeled numerically (Callaway and Koblinsky, 1977). Station locations would be altered as the need arises once the actual sampling program begins.

Where bottom sediments are extremely viscous (very slow dispersal e.g., congealed oil) little turbidity might be experienced in the water column; however, pollutants may still be relocated. In this case, underwater television may be a necessary adjunct or possibly the only feasible method of observation. Its use should receive strong consideration. Even in the case of visible turbidity clouds, a videotape of the relative differences between

the different dredge systems might prove to be of as much or more value than quantitative measures of light transmission, suspended solids and temperature. Another possibility consists of tracking the suspended matter acoustically as has been done in the New York Bight (Proni, et al., 1976).

SUMMARY

In summary several questions remain unanswered about Japanese specialized dredges. The one of primary concern at this point is their relative efficiency to minimize resuspension of bottom sediments and how that efficiency compares to more conventional hydraulic dredges. Therefore, we propose the following preliminary experimental approach, the intent being to make use of a continuous observable field (total suspended solids vs. percent light transmission) in conjunction with discrete water samples to:

1. Define the relative ability of the two dredge types to minimize resuspension of bottom sediments and;

2. To assure that sampling is done in the proper location to observe any differences. In the event of a highly viscous sediment, recourse to an alternative, e.g., TV observation method, may be required. Data could be presented in a manner similar to Callaway, et al. (1976). Water temperature and salinity would also be measured in the working area and a number of grab samples at the working site would be analyzed for other pollutants to include, but not to be limited to, THg and PCB. Some samples would be split with half of the same sample being shipped to the United States for analysis. This would allow us to determine if any differences exist in analytical results and how we might handle the differences in a jointly produced report. This information will also permit us to make better use of and to interpret other Japanese results which may be available to us.

Ideally, it would be most desirable to make the proposed measurements for the oozer dredge while it worked alone, then make the same determinations for the hydraulic dredge as it worked alone. This should be done under the same conditions as nearly as possible and at the same site.

It is anticipated that it will require one week to make final on-site plans and preparations for conducting the field sampling program once equipment, vessel and scientific field party are on hand. It will require approximately one more week to make measurements with a hydraulic dredge operating alone and an additional week to repeat the measurements with the oozer dredge. Some time will be required to dismantle, repack and ship materials back to the U.S. as well as do some of the preliminary examination of the data. A total of 3-4 weeks is anticipated. Agreement on the results and subsequent publication of same will require another month to six weeks of drafting and exchange of critical review.

It is proposed that the field investigation begin the first of March 1978. It is anticipated that at a minimum, two technical staff members from the Corvallis Laboratory and a Corps of Engineers representative who is totally familiar with dredging should be involved in the field experiments.

Lack of familiarity with Yokkaichi Port by the United States (sampling vessels, possible laboratory facilities, etc.) prohibits preparation of a final demonstration plan and this paper provides only preliminary ideas which are subject to modification. It should also be recognized that the proposal addresses only the first step toward evaluating the Japanese dredging technology. Several other questions remain to be addressed at a later time.

POSTSCRIPT

While this preliminary plan was not presented during the formal conference at Easton, Maryland, it was discussed at length when the Japanese delegation visited the Corvallis Environmental Research Laboratory following the meeting. They chose to take the plan under advisement and to let us know at the earliest possible date what their decision concerning the joint project would be.

In January 1978 the United States was notified by the Japanese Ministry of Transport (Mr. Hiroshi Suda) that that Agency had designed a research plan and it would be conducted at Port Yokkaichi on March 8, 9 and 10, 1978. United States representatives were invited to observe the demonstration experiment. Since the United States was not invited to play a "hands on" role in the experiment it was decided only one representative from EPA (Spencer A. Peterson) and one from the Army Corps of Engineers (William D. Barnard) would participate as observers.

The experiment began on schedule March 8, with the oozer dredge system operating. The dredge crew appeared to be well organized and the experiment proceeded without problems. The next day, March 9, the cleanup dredge system performed in the same area. This experiment also went well except for the apparent hitting of a raised mound of sediment by the dredge head which created noticeable turbidity on the subsurface television monitoring system located 3.5 m above the sediment surface, immediately over the dredge head.

Results and interpretation of the experiment were sent to the Corvallis Environmental Research Laboratory in April 1978. They were supplied by Mr. Hiroshi Suda of the Japanese Ministry of Transport. The United States was subsequently authorized by that Agency to publish results of the experiment. They are published exactly as they were received except for retyping and drafting, an occasional spelling correction and standardization concerning format.

JAPANESE DREDGING DEMONSTRATION PROJECT RESULTS

The results and conclusions of the dredging demonstration at Port Yokkaichi, Japan are presented on the following pages. They were made available by Mr. Hiroshi Suda, Director of the Environmental Protection Division of the Japanese Ministry of Transport. All information on these pages resulted from work conducted by the Japanese Government. There has been no attempt by the editors to interpret or evaluate these data. They are published here so that individual readers may draw their own conclusions.

RESULTS OF THE INVESTIGATION OF TURBIDITY GENERATED BY DREDGES AT YOKKAICHI PORT

1. Outline of the investigation

This investigation was executed at Yokkaichi Port using two specialized dredges to gain the quantity of turbidity generated by dredging works. The outline of the investigation is shown in Figures 1, 2, 3 and 4 and Tables 1 and 2.

Fig. 1 Outline of investigation site

Fig. 2 Trace of float

Fig. 3 Dredged materials (Particle size accumulation curve)

Fig. 4 Arrangements of measuring points

Table 1 Meteorological observations

Table 2 Dredged materials (Grain size distribution)

2. Measuring items

Item	Points	Period	Method
(water quality) turbidity	St. 1, St. 2 (3 layers), St. 3, St. 4	Approx. 100 minutes continuously	turbidity meter
concentration of SS	St. 1, St. 2, St. 3, St. 4, suction head (2 points)	every 5 minutes	pump sampling
(bottom sediment) grain size distribution	dredging site	before dredging	-----
(marine phenomenon) velocity of tidal current	St. 2	Approx. 100 minutes continuously	propeller current meter
ditto	-----	every ten minutes	float
(other) volume of dredged materials	-----	during dredging	-----
position of suction head	-----	during dredging	-----

3. Results of Investigation

Concentrations of suspended solids at Stations 1 through 4 and 2 points around suction head are shown in Tables 1 and 2 respectively, which were measured through filtration of the sampled water in the laboratory.

On the other hand, time history of turbidity shown in Figures 5, 6, 7 and 8 is gained through converting the continuous records of turbidity level measured by turbidity meters on boats into concentration of suspended solids. (As there is no conspicuous difference of concentration of suspended solids between the two cases shown in Tables 3 and 4, time history is shown in one case here.)

Figure 9 shows the comparison of the concentration of suspended solids around the suction head between conventional dredges and specialized ones.

The value of conventional dredges (pump dredge with cutter) shown in Figure 9 was measured at Yokkaichi Port in 1974 for the same soil as in this investigation.

Judging from Figure 9, we can conclude that the concentration of suspended solids around the suction head of specialized dredges is very low, approximately one-tenth that of conventional ones.

Dredging Condition

Type of dredger			Conventional		Specialized	
Date			1974.11. 6-22		1978.3. 8-9	
Dredge site			near North wharf in Yokkaichi port		near Asahi breakwater water in Yokkaichi port	
Dredged material (wt.%)	Sand		9		11	
	Silt		58		41	
	Clay		33		48	
Water depth (m)			12		14	
Test No.	12	#	2C1-1	2C1-2	CHOSA1	CHOSA2
Moving distance of spud with one swing (m)		(1)	2.03	2.07	2.5	2.5
Swing rate (m/min)		(2)	7.0	7.2	5.1	5.0
Depth of cut (m)		(3)	1.7	1.9	0.53	0.49
Discharge pipe diameter = D (m)			0.61	0.61	0.56	0.45
$\pi D^2/4$ (m ²)		(4)	0.292	0.292	0.246	0.159
Percentage of mud content (%)		(5)	21.6	29.1	---	---
Flow velocity in discharge pipe (m/sec)		(6)	4.91	4.66	1.41	3.14
Apparant excavated volume (m ³ /h)		(7)				
(1)(2)(3).60			1,149	1,699	405	368
Virtual dredge production (m ³ /h)		(8)				
(4)(5)(6).3600/100			1,115	1,426	324*	294*
Mixture flow rate (m ³ /h)		(9)				
(4)(6).3600			5,163	4,900	1,251	1,800

: Test number shown in Figure 9.

* : Value of (7) x 0.8, where 0.8 is empirical constant.

TABLE 1. THE RECORD OF METEOROLOGICAL OBSERVATIONS

Date	Test No.	Dredging Time (hr-min)	Wind direction	Wind (m/s)	Wave Height (cm)	Tidal Current direction	Tidal Current (m/s)	Weather
3/8	CHOSA-1	8:30-9:50	W	1.0	10	--	<0.05	Clear
3/9	CHOSA-2	9:00-10:20	NW	1.0	10-20	--	<0.05	Clear

TABLE 2. DREDGED MATERIALS

Gravel (%)	Sand (%)	Silt (%)	Clay (%)	(*1) U_c	(*2) U_c	Name
0.4	11.4	41.2	48.0	11.88	0.64	Silty Clay

$$(*1) : U_c = \frac{D_{60}}{D_{10}}$$

$$(*2) : U_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$$

TABLE 3. AN ANALYSIS TABLE OF SUSPENDED SOLIDS

CHOSA-1

No.	S1 ¹	SS (mg/l)				time	SS (mg/l)	time	
		S2	S3	S ²					S4
				center ³	right				
1	2	10	8	6	4	8 32 30	4	8 20	
2	4	8	6	6	4	8 35	6	8 25	
3	10	9	8	2	2	8 37 30	2	8 30	
4	76	8	5	4	8	8 42 30	8	8 35	
5	6	10	9	4	19	8 45	2	8 40	
6	6	4	5	5	11	8 47 30	2	8 45	
7	8	9	6	4	4	8 53	2	8 50	
8	6	6	9	7	6	8 55 30	1	8 55	
9	9	7	7	2	3	8 58	1	9 00	
10	2	3	7	5	7	9 24 30	2	9 05	
11	2	5	6	5	7	9 27	14	9 10	
12	2	4	15	2	5	9 29 30	4	9 15	
13	4	4	18	5	8	9 35	5	9 20	
14	5	4	4	7	15	9 37 30	3	9 25	
15	4	6	6	2	9	9 40	5	9 30	
16	4	7	3	4	6	9 46			
17	8	8	6	4	8	9 48 30			
18	4	7	7	4	8	9 51			

¹ S1 ~ S4 = the observing boat² S = dredge.³ "Center" and "right" = the position of sampling points around suction head.⁴ Dredging continued from 8:30 to 9:50.

TABLE 4. AN ANALYSIS TABLE OF SUSPENDED SOLIDS

No.	S1 ¹	S2	S3	S ²		time	SS (mg/l)
				center ³	right		
1	2	3	4	4	5	9 02 30	5
2	2	4	4	7	7	9 05	7
3	2	4	4	6	4	9 07 30	5
4	2	3	4	4	4	9 12	4
5	5	4	4	8	4	9 14 30	4
6	6	4	2	6	10	9 17	2
7	6	8	8	15	4	9 21 30	2
8	6	2	4	5	24	9 24	0
9	4	1	3	10	13	9 26 30	1
10	8	1	1	2	9	9 53	2
11	21	8	3	5	4	9 56	0
12	13	15	1	2	8	9 58 30	2
13	6	9	1	8	18	10 04	2
14	12	6	2	8	12	10 06 30	2
15	6	9	2	9	12	10 09	2
16	7	8	5	3	10	10 15	2
17	9	8	2	3	3	10 17 30	2
18	8	5	5	9	8	10 20	2
							8 50
							8 55
							9 00
							9 05
							9 10
							9 15
							9 20
							9 25
							9 30
							9 35
							9 40
							9 45
							9 50
							9 55
							10 00

¹ $S1 \sim S4$ = the observing boat

² S = dredge.

³ "Center" and "Right" = the position of sampling points around suction head.

⁴ Dredging continued from 9:00 to 10:20

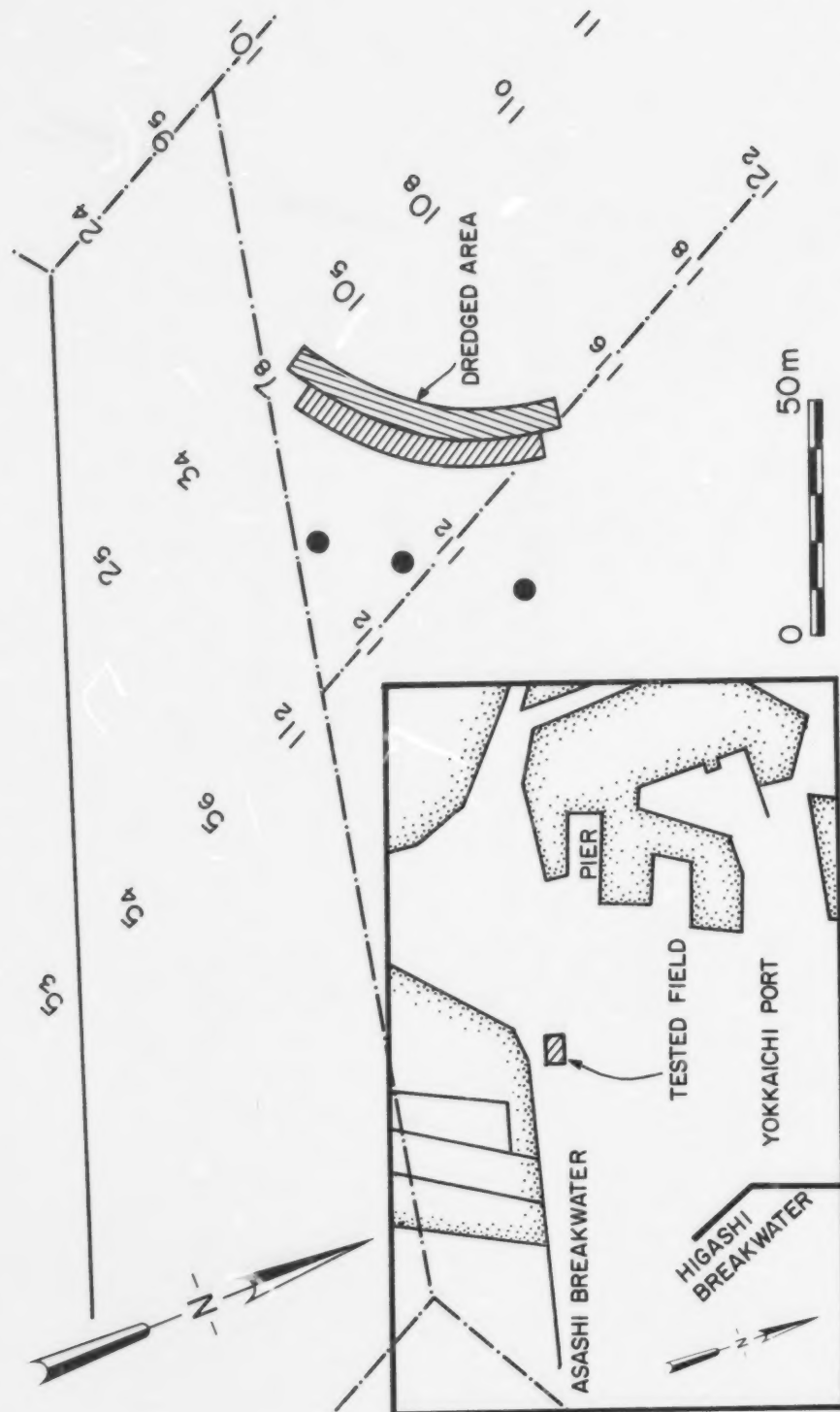


Figure 1. Investigation site

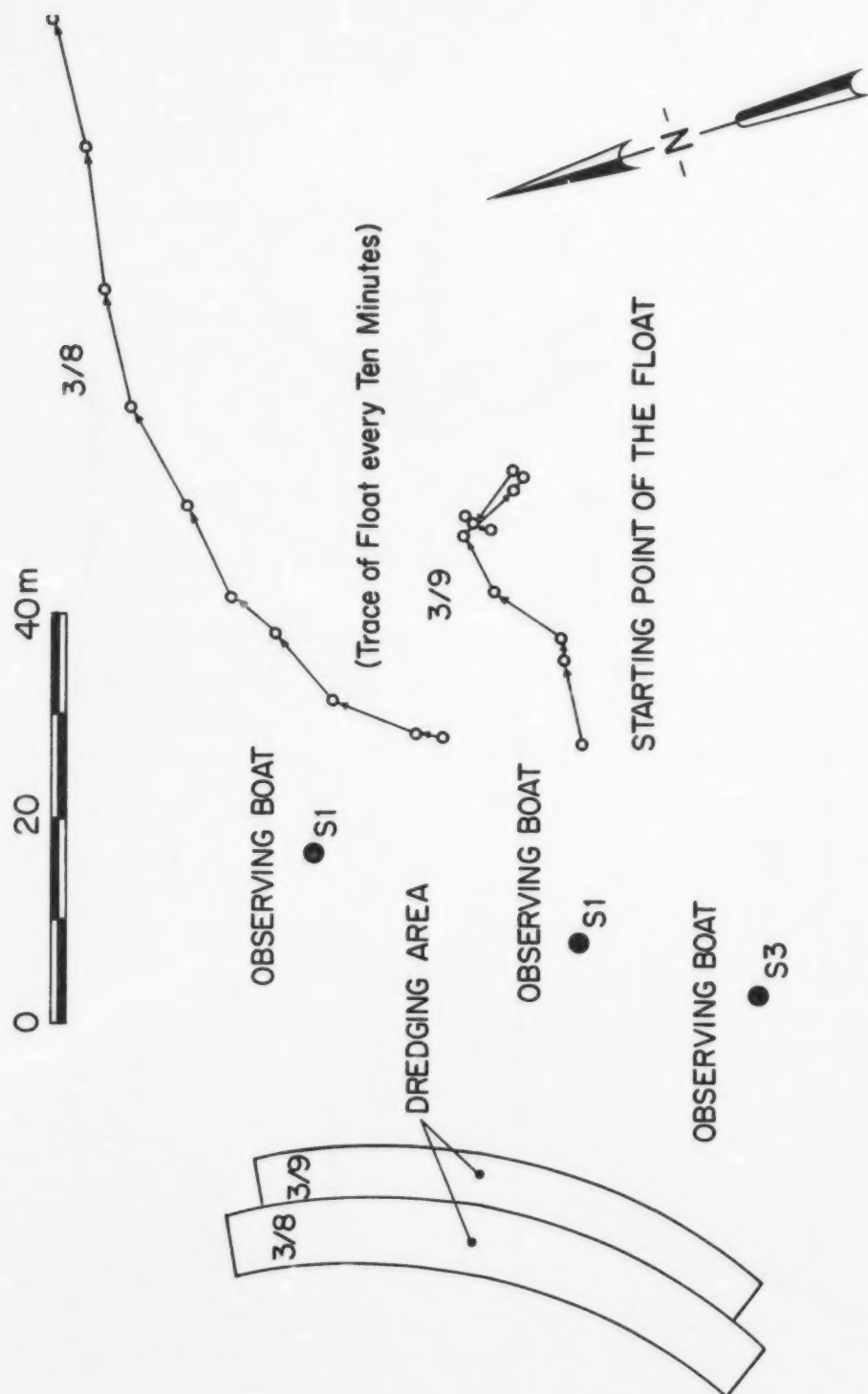


Figure 2. Investigation of tidal flow by float.

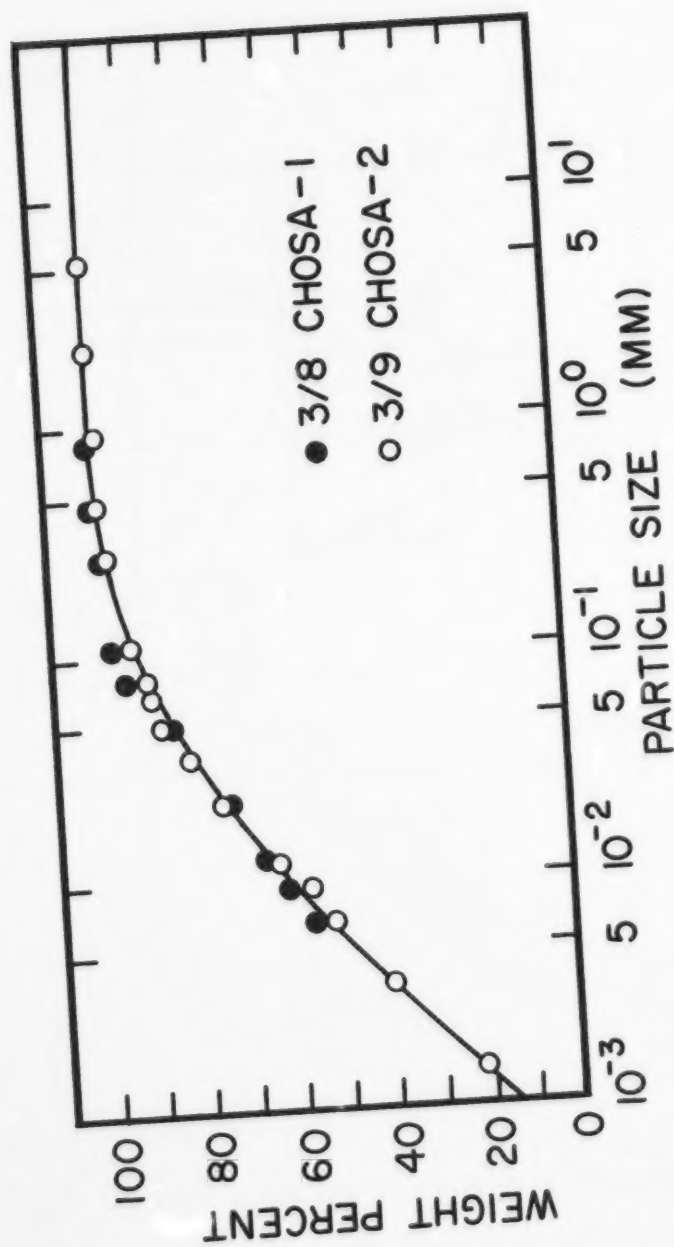
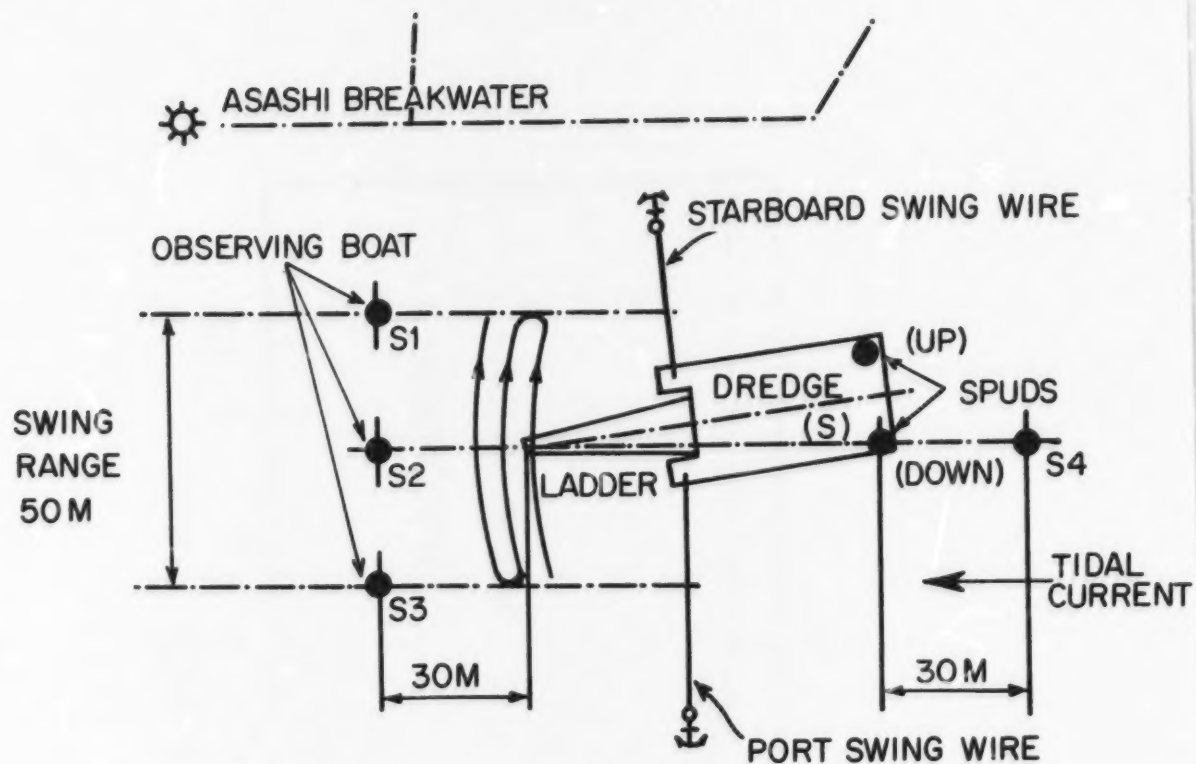


Figure 3. Particle size accumulation curve.



Horizontal arrangement of observing boat.

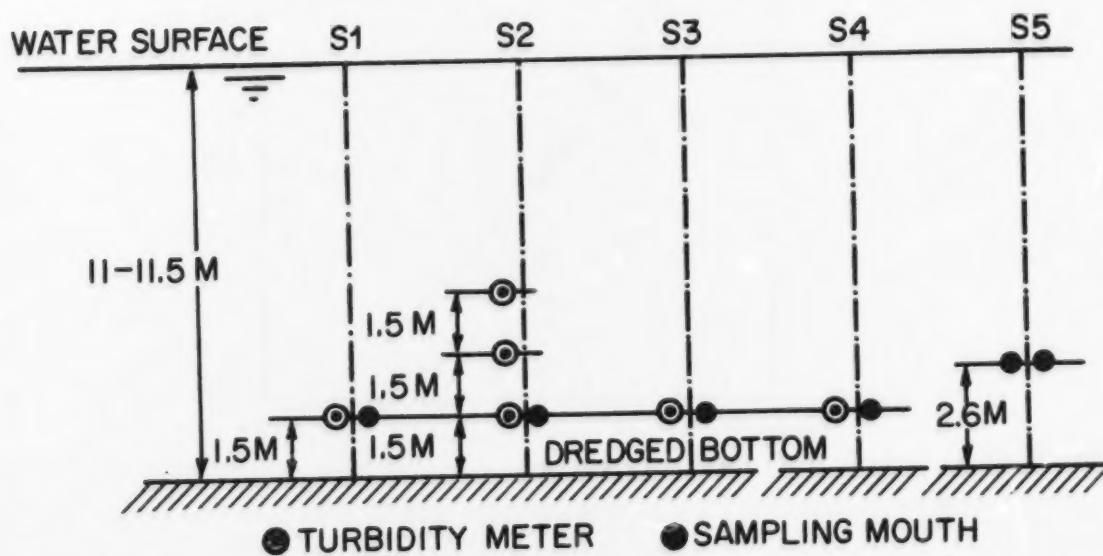


Figure 4. Device arrangements for turbidity measurements.

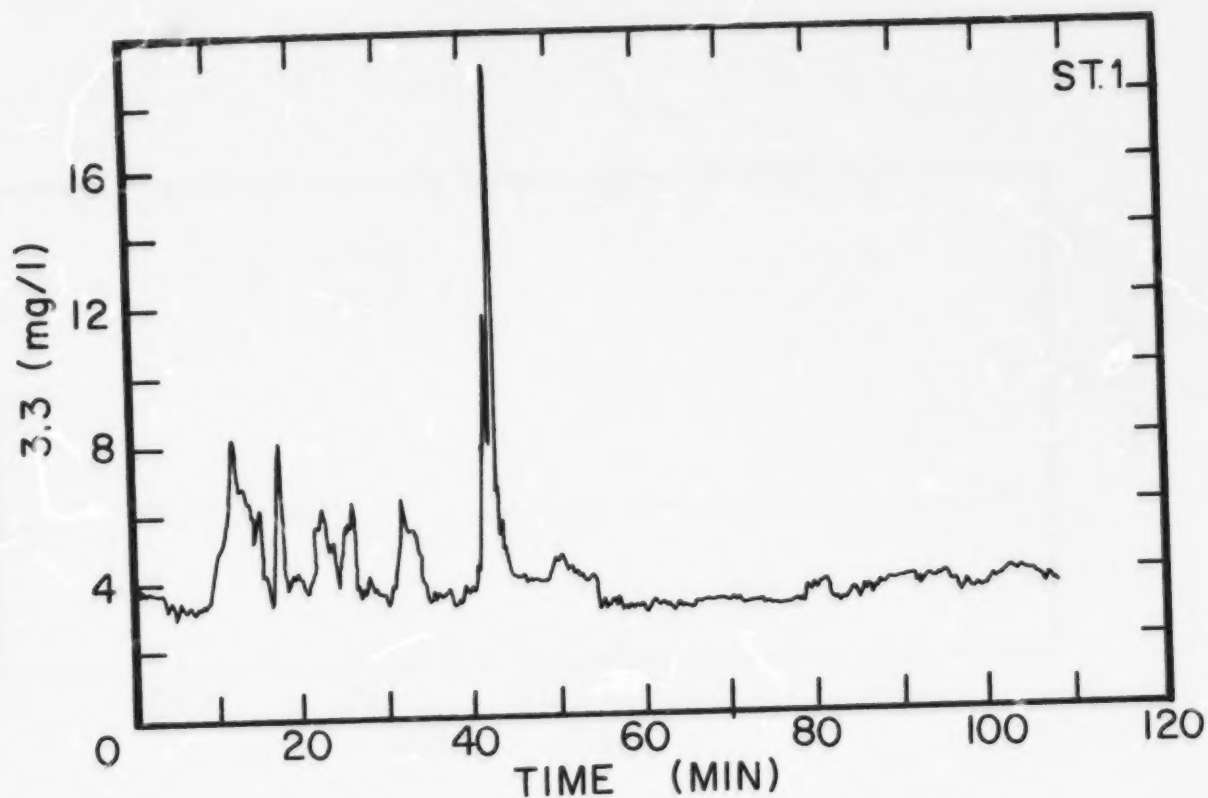


Figure 5. Time history of suspended solids

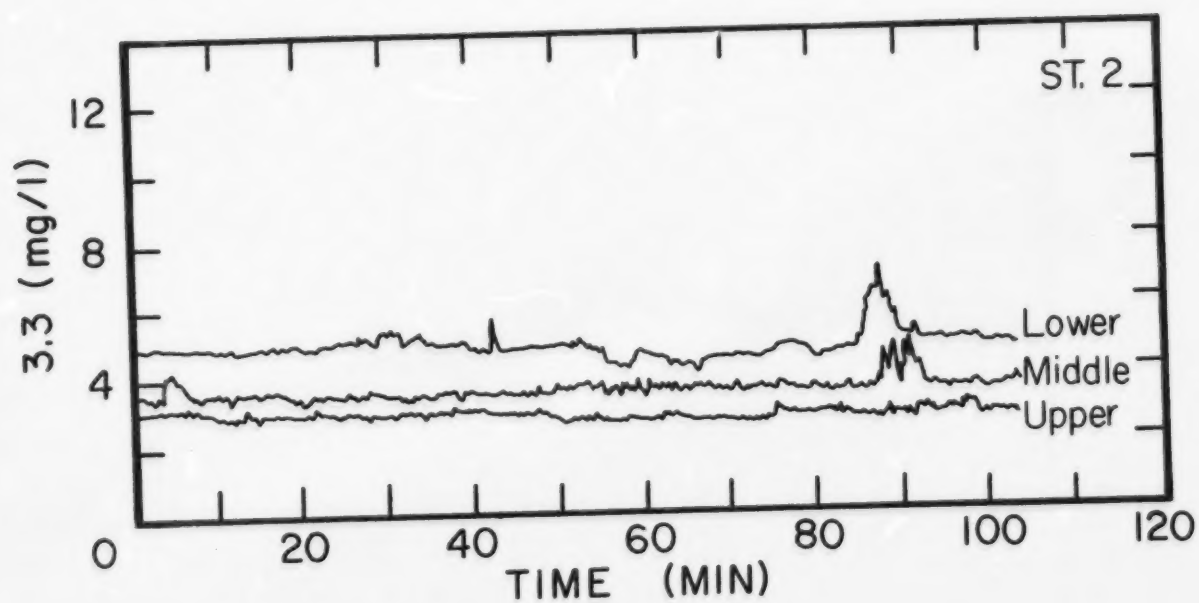


Figure 6. Time history of suspended solids

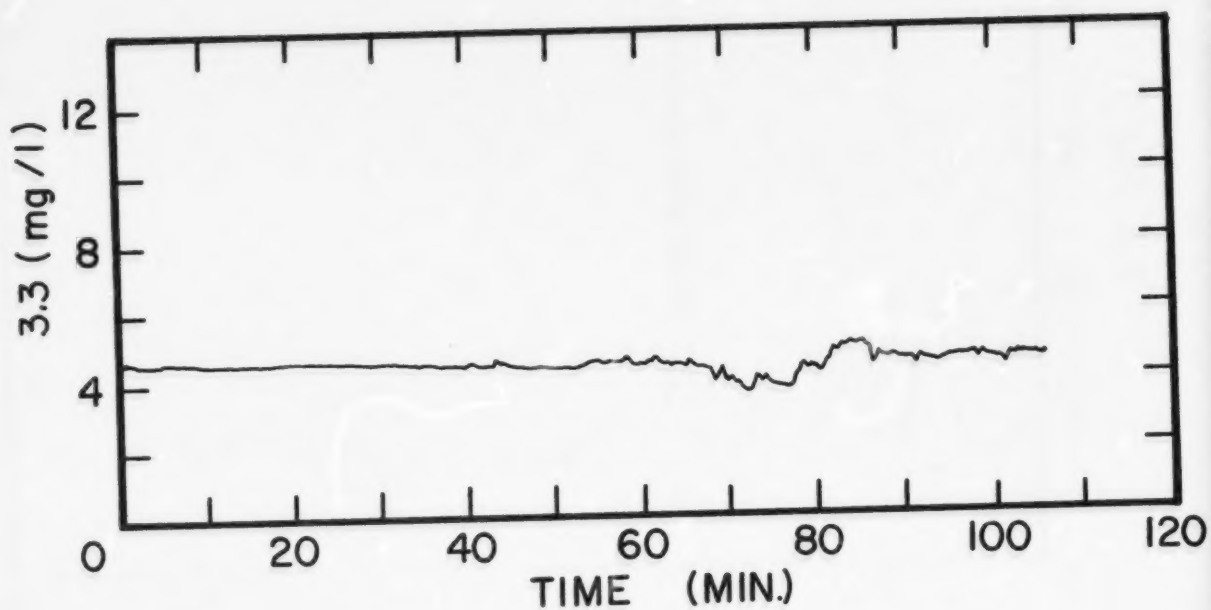


Figure 7. Time history of suspended solids

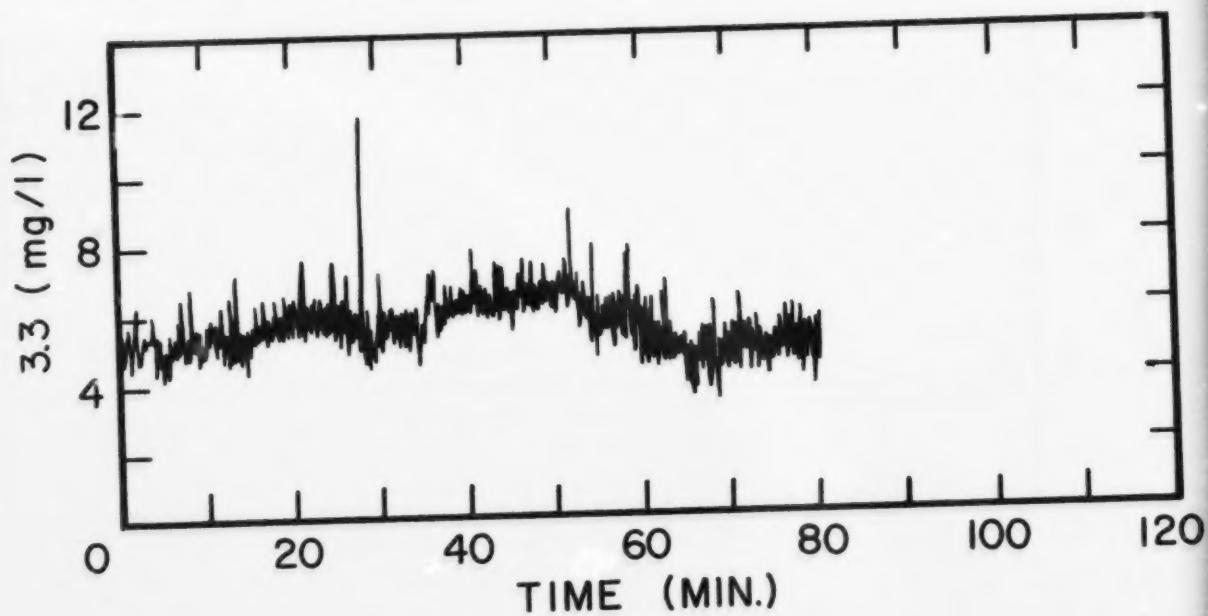


Figure 8. Time history of suspended solids.

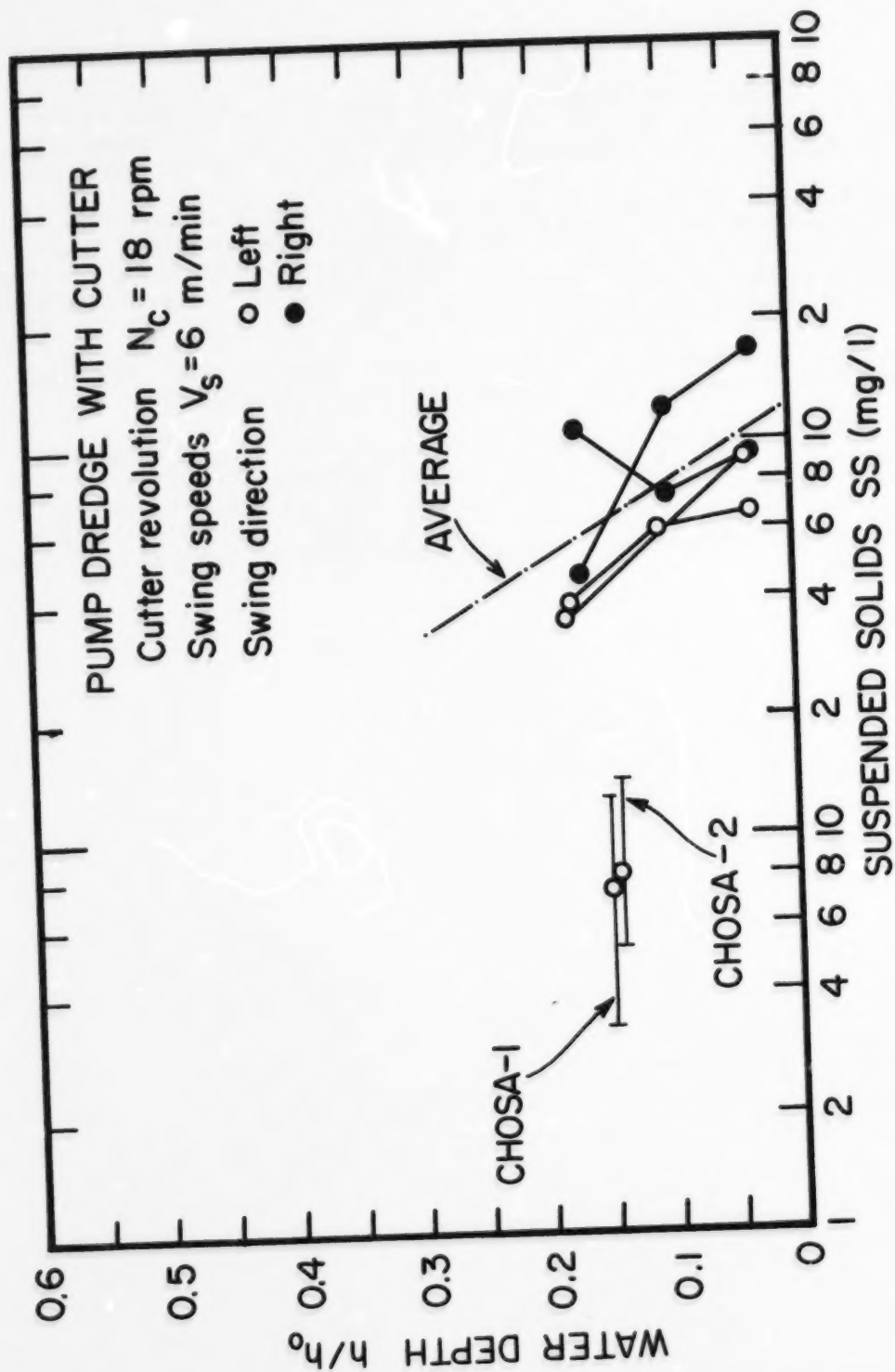


Figure 9. Comparison of SS around suction head between conventional dredges and specialized dredges.

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